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Forecasting Research

Forecasting Research Division
Technical Report No. 170

Forecasting thunderstorms in "Spanish Plumes"

by

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5 July 1995

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Contents

1. Background and aims

2. NWP Verification - by the Central Forecasting Office (CFO)
   2.1 Limited Area Model (LAM)
   2.2 Mesoscale Model (MES)

3. Introduction to the two case studies
   (a) 12 July 1994
   (b) 27 July 1994

4. Details of the 12 July 1994 case
   4.1. Synoptic situation
   4.2. The forecasting problem
   4.3. Possible causes and proposals for investigation
   4.4. LAM re-runs and results
   4.5. Discussion and future work

5. Details of the 27 July 1994 case
   5.1. Synoptic Situation
   5.2. The Forecasting Problem
   5.3. Justification for re-runs
   5.4. Model re-runs and results
   5.5. Discussion and future work

6. Recommendations
   6.1 For Forecasters
   6.2 For Observations
   6.3 For Modellers: assimilation/ model development

7. Acknowledgements

References
Annex: Input to the model re-runs

1. Background and aims

The contents of this report were produced for the CFO/FR Workshop held on the 26th January 1995.

This study concerns the forecasting of heavy rain and thunderstorms that develop in very warm potentially unstable air over France, Spain and the Bay of Biscay and move north-east over the UK in the south-westerly flow aloft on the forward side of an upper trough. The storms tend to affect the UK overnight. The synoptic situation often has the ingredients identified in Fig. 1.1 - a weak cold front moving east or southeast across England, a heat low over France and an upper trough moving east towards the UK. The heat low is associated with a plume of very warm air, easily identified in charts of 850 hPa wet bulb potential temperature (θw), extending northwards from Spain over France; such situations are therefore known as "Spanish Plumes".

The most severe thunderstorms form in the warm air ahead of the cold front (See e.g., McCallum and Waters 1993). Section 2 shows that, at present, the Local Area Model (LAM) of the UK Unified Model is not good at forecasting the location, intensity and amounts of rain in these situations. There were 13 such episodes in the summer of 1994, two of which were chosen for detailed study.

Satellite imagery shows that convective cloud can develop remarkably quickly into major storms, some into large mesoscale convective systems (MCSs). This highlights the forecasting problem. Although the storms will sometimes be set off by, for example, low-level convergence, there is often no obvious reason for the location of the first storms. The atmosphere in these situations is often finely balanced: the air is potentially unstable and relatively small amounts of induced vertical motion can be sufficient to release the instability.

In the summer of 1994, some MCSs had a significant effect on the weather over the UK for the following 24 hours as they developed and moved north-east, generating cloud and rain, and much cooler conditions than forecast by the model. In some cases, the model guidance was still for a continuation of high temperatures. MCSs can also significantly distort the upper winds which may then influence developments downstream, as well as invalidating the wind forecast for aviation .

The aims of this study were to examine two Spanish Plume cases to serve as a basis for:

recommending ways to improve the model forecast,

helping forecasters to interpret signals from a variety of sources in the best possible way.

2. NWP Verification - by the Central Forecasting Office (CFO)

2.1 Limited Area Model (LAM)

The following information shows the LAM performance of rainfall forecasts over the

UK, as assessed by the Chief Forecaster, for 68 forecasts during the 13 episodes in 1994. Data times are 0000 UTC and 1200 UTC. These figures apply to the T+24 and T+36 frames.

A: Excellent forecast
B: Good guidance but some variations in intensity or position of precipitation areas.
C: Poor guidance (i.e. precipitation or thunderstorms missed or grossly over-forecast).

+: Over-forecast of rainfall
-: Under-forecast of rainfall
In the rest, there was no significant bias.

A	9	
B	35	(+ 9, -12)
C	24	(+10, -7)

These numbers show that there were far more 'C' forecasts than 'A' forecasts. (Interestingly, of the 9 'A' forecasts, 8 were associated with diffluent upper troughs.) There was no significant difference between the statistics for T+24 and T+36. The Chief Forecaster does not assess the T+12 forecast but subjective analysis gives the impression that the statistics for T+12 would be similar.

2.2 Mesoscale Model

In the case of the 52 mesoscale model forecasts (MES), the scores, applied to the whole forecast period up to T+18 (data times of 0000 UTC and 06 UTC), were as follows:

A	15	
B	24	(+4, -3)
C	13	(+5, -6)

(Note however that the 0000 UTC forecasts do not cover the main thunderstorm period). Of these, 28 gave similar guidance to the LAM, in 18 the MES was considered better, and in 6 the LAM was better.

3. Introduction to the two case studies

Although the LAM is mainly used for forecasts of precipitation and other variables for 18 to 36 hours ahead, a 12-hour forecast is useful to fine-tune the previous forecasts. In the two cases studied, the 1200 UTC operational LAM failed to produce convective rain over south-east England by T+12. In both cases, the key upwind area was over the Bay of Biscay where there were few observations. In July 1994, the MES was run at 0000 and 0600 UTC, the former out to T+18 hours, so only the 0600 UTC run was relevant to the study.

(a) 12 July 1994

The striking aspect about this case was that none of the model forecasts from data times on the 12th had showers overnight in southeast England. The 12/0600 run of the MES also failed to produce showers, not surprisingly as the relevant information would be advected across the boundary from the LAM. Thus there was no warning of the overnight rainfall of up to 9 mm in southeast England.

(b) 27 July 1994

In this case, a mesoscale convective system (MCS) developed during the night, affecting eastern England with widespread heavy rain. In this area the 27/0000 run of the LAM developed light showers and the 27/0600 run had heavy showers, although the precipitation was not as severe as that which did occur. Consequently CFO correctly maintained a forecast of thundery showers southeast of a line from the Wash to Dorset even when the 27/1200 run had dry weather over the area.

The 27/0600 MES extended the activity of an old cold front southwards from the North Sea across eastern England after 27/2000, and so had a band of showers crossing southeast England from the west near the time of the thunderstorm development. However, this evolution was contrary to observations which showed that the showers and thunderstorms came from the south.

4. Details of the 12 July 1994 case

4.1. Synoptic Situation

A weak cold front was moving slowly and erratically east across the UK (Fig. 4.1.1). 850 θw values reached 16 to 18°C over England in the warm air ahead of the front. At 13/0000 the western edge of the high θw values was rather indistinct, lying from Lancashire and the Welsh border to Brest.

Shallow heat lows developed over France and England on the 12th. Low level winds over southern England were light, with sea breezes around the coast during the day.

In the upper air (Fig. 4.1.2), a 500 hPa trough was moving slowly east and relaxing; by 13/0000 its axis was lying over central Ireland and extended southwards to just west of Corunna.

There were isolated thunderstorms over northeast England during the evening of the 12th (Fig. 4.1.3) and these moved northeast over the North Sea. They were associated with the cold front and unconnected with the later developments in the south.

At 12/1800 there were no thunderstorms over France but Ac castellanus had been reported in the Channel Islands throughout the afternoon. Over France, no doubt, sightings of Ac castellanus were not available because of the extensive automatic weather station system there. However the station at Caen (C on Fig. 4.1.3), reported Ac castellanus at 1500 and 1800.

The first lightning from the overnight storms (Fig. 4.1.3), was at 12/2100 in the Caen/Cherbourg area. These storms were generated at medium-levels. Thereafter thunderstorms developed along two parallel lines orientated SSW to NNE over southeast England (seen, for example, on the radar picture at 13/0300, Fig. 4.1.4). In this area, total accumulations of rainfall, observed at 13/0900, were locally at least 8 or 9 mm.

4.2. The Forecasting Problem

The forecast issued by CFO at 12/1520 indicated that southeast England, the Midlands and East Anglia would be dry. This guidance concurred with the LAM, which had no indication of showers developing overnight (12-13th). Fig. 4.2.1 shows the LAM forecast from data time 12/1200 .

Although flow behind the upper trough was weak (Fig. 4.1.2a), the LAM was developing a shallow cut-off over southeast England late on the 13th. This was highlighted in the CFO forecast issued at 12/1520 as the cause of the destabilisation leading to deep convection on the afternoon of the following day - the 13th.

A summary of the LAM runs is:

Data time	Forecast
12/0000	no ppn overnight and only 2 shower symbols at 13/1200
12/0600	no ppn until 13/1200
12/1200	no ppn in south and east England until 13/1200
12/1800	ditto
13/0000	no ppn throughout the forecast.

Thus, no run of the LAM gave any indication of showers developing during the night of the 12th to 13th. Of the two cases studied in this Report, this was probably the most difficult for the forecaster as the consistent message from the LAM (and the 12/0600 MES) was for dry weather.

The MES run at 12/0600 (Fig. 4.2.2) had a surface trough at 13/0000 from the Humber southwards. The convergence in the trough (indicated by the surface winds) did not extend to the south coast and the storms at that time were over the English Channel. However, the presence of a trough over southern England might well have enhanced their development over England once they had formed further south. It might also help to explain their linear organisation over southeast England.

4.3. Possible causes and proposals for investigation

(a) Low-level convergence.
The development of the thunderstorms along a line (or initially two lines in this case) may suggest that a main cause was convergence at low levels. However the lines did not tie up with favoured areas of sea-breeze convergence so a low-level trigger over France seems unlikely.

(b) Short-wave upper trough (swt).
A valuable and independent source of information is satellite imagery. In this case the

pattern in the water vapour (WV) imagery delineated the frontal band of moisture MM' (Fig. 4.3.1) but did not show any significant swt, ahead of which positive vorticity advection might lead to ascent and consequent release of potential instability. (The wave, apparent near M, drifted slowly southeastwards.)

(c) Humidity.
Forecast model humidities over southeast England were low at 13/0000, too low to produce any convective cloud; see the model sounding for Hx in Fig. 4.3.2 (the station locations are shown in Fig 4.3.1a). In contrast the radio-sonde sounding at Hx (Fig 4.3.3) shows that the air was much moister just ahead of the thunderstorms, especially between 800 and 550 hPa. It is postulated that in the LAM the air upwind, over Biscay, had been too dry. Re-runs with moister air are described in Section 4.4.

4.4 LAM re-runs and results

For the experiments, version 3.3 of the LAM was used, which included a modification to enhance observed radio-sonde humidities above 80% (Bell 1994). All re-runs were based on a data time of 12/1200. The control run, using this version, was very similar to the operational run on the 12th July.

(a) Extra simulated data (Trial 1)
In order to match the high humidities between 750 and 550 hPa in the pre-storm environment, shown by the ascents at Hy and Hx at 13/0000 (Fig. 4.3.3), increased mid-level humidity was inserted in the LAM over Biscay, based in part on the moisture distribution identified on the water vapour images (see Annex for details). As no evidence of a short-wave trough was seen in the satellite imagery and the model wind analysis seemed to be reasonable, the winds were unchanged.

This run produced showers by 12/1800 near Brest, moving east to lie from Cherbourg to Bristol at 13/0000 (Fig. 4.4.1). This development was early and a little to the west of the actual convection but would have provided the forecaster with useful guidance, even though the rainfall accumulation was too small.

In this re-run the model humidities at 13/0000 over northwest England and the west Midlands (A and G in Fig. 4.4.2) were too high but those to the south and east (J and Hx) were probably about right (stations are located in Fig. 4.4.1). The main problem when changing humidities is to know by how much, where and at which levels to increase the humidity. Obviously the humidities had been increased over too large an area (see below in (c)).

(b) Omission of data (Trial 2)
In this re-run, no extra data were inserted but the humidity observations were omitted from the soundings at Corunna and Brest (Cr and Br in Fig. 4.4.1). This trial was carried out because it was thought that, during assimilation, the dryness in these soundings might have extended westwards to reduce the humidity at the southern end of the cold front and in any moist air ahead of it. However this run was not significantly different from the control run because the observations from these soundings were similar to the model background above the radio-sonde stations.

(c) Satellite humidity data (Trial 3)
Locally-retrieved profiles of humidity from polar orbiting satellites have recently been accomplished in the UK Met Office Global Sounding System (GLOSS) but only for cloud-free positions (see Gadd et al 1994). On 12th July 1994 there were a few retrievals in the Bay of Biscay area at 12/0537 and 12/0757. At 500 hPa the retrieved values were similar to the model background but at 700 hPa, over a limited area, the retrieved values of humidity showed a significant moistening compared to the background values (Fig. 4.4.3). There was a marked increase to over 80% in northeast Biscay.

These data (see Annex) were assimilated to produce the model analysis of relative humidity at 12/1200 UTC shown in Fig. 4.4.4. By this time there are no high values at 700 hPa but a lozenge of moister air is positioned over northwest France. In the re-run of the forecast (Fig. 4.4.5), this area became narrower and moved slowly northeast to lie near the observed area of thunderstorm development. In this model run, no showers were produced but the model soundings over southeast England had moistened at 700 hPa - at Hx the dew point increased by 5°C (compare Figs. 4.4.6 and 4.3.2). Also note the drier air at J and G in Fig. 4.4.6 compared to Fig. 4.3.2. Thus there was a slight positive impact from the GLOSS data.

4.5 Discussion and future work

The idea that the dry Corunna ascent at 12/1200 dried out the air over Biscay was not supported by the evidence of the model re-runs in this case (but see the next Section for a contrary case). The model just did not have enough humidity initially in the middle levels over Biscay for convection to develop later over northern France and the UK. When more humidity was injected (Trial 1), showers developed, approximately in the right area.

However, in reality, thunderstorms developed along quite a narrow zone, initially appearing as two fairly straight lines on the radar image. Judging from this radar imagery, the convection was limited to lines less than 50 km wide (i.e. as small as the gridlength of the LAM but resolvable by the MES). Model airflow trajectories could be used to track areas of high and low humidity air, especially where they fan out into deformation zones which are often straight or only slightly curved. It is the juxtaposition of these different airflows that can create zones favourable for convection. (The over-running of low θw air at a split cold front is a well-documented example). If these diagnostics were available to the forecaster, they would give him a better grasp of how the humidity pattern had developed and, combined with temperature profiles, could alert him to where the stability was decreasing.

The WV imagery showed narrow bands of moisture during the morning of the 12th ahead of the main frontal band of moisture. These, no doubt, were mainly at upper levels but this case demonstrates the importance of assessing humidities also at middle levels.

From the data time of 13/0000 the MES did produce a good forecast of the evolution of the precipitation in southern England (Fig. 4.5.1), whereas the corresponding LAM still had no showers. Of course, the 13/0000 runs were too late to be of any value to

the forecaster but it is instructive to note the differences due to the different resolutions and assimilations (Bader 1995). In the model ascents for Hx and Hy at T+0 the MES had more moisture at medium levels and more ascent at Hx than in the LAM (Fig. 4.5.2). Winds were very similar to those in the LAM. The development of these storms may have been on too small a scale for the LAM in such a finely balanced situation. This case shows that the MES can be valuable in picking up important small scale variations.

In July 1994 the MES was not yet run at 12/1200 and 12/1800 and the southern boundary was about 48°N. It would be useful to run the MES at these times with its area extended southwards over France and Biscay. Even using the present boundaries, the 12/1200 run, and more especially the 12/1800 run, of the MES might have produced a better forecast as the unstable Ac cloud over north France would have influenced the MES analysis (Wright 1993).

5 Details of the 27 July 1994 case

5.1 Synoptic Situation

Late on the 27 July a weak cold front, with a minor wave, was lying from the Wash to Portland and expected to drift slowly east (Fig. 5.1.1). A shallow heat low forming over central France on 27th extended north overnight. At low levels there was high θw air over the Continent and the southeast of England.

There was an upper trough just to the west of the UK (Fig. 5.1.2a). The LAM forecast this trough to move east and the northern part relax as a new trough extended southwards further to the west, making the southern portion slow-moving just west of Iberia. This is what happened (Fig. 5.1.2b).

Thunderstorms developed around 27/1500 over Biscay at 47°N 08°W. These moved slowly northwards (A in Fig. 5.1.3) and dissipated between 1800 and 2100. An isolated thunderstorm also developed over Brittany at 1500 but there was a rapid escalation of thunderstorm development between 1800 and 2100 (see the WV sequence in Fig 5.1.4). These storms again originated over Biscay just ahead of a sharpening upper trough and moved into southeast England, East Anglia and the East Midlands. They were part of a mesoscale convective system (MCS), (Fig. 5.1.4d). As a result, there was thundery rain over much of eastern England during the morning and early afternoon of 28 July (Figs. 5.1.5 a,b). The precipitation from the Midlands to Lincolnshire was initially a separate band which tended to merge with the storms further east by 28/0900. Amounts of rain were as high as 30 mm in northern Norfolk and in Lincolnshire.

5.2 The Forecasting Problem

Although the 850 θw field was well predicted, the 27/1200 LAM (Fig. 5.2.1) did not forecast any precipitation over England and Wales for 36 hours (apart from a few showers near the Wash). Earlier forecasts were better; the 27/0000 run and especially the 27/0600 run had some showers over southeastern parts of the UK (the latter having up to 8 mm of rain over Cambridgeshire). Successive Chief Forecasters were forecasting thundery showers to develop in the area southeast of a line from the

Wash to Dorset. This was an improvement over the model guidance but did not cover the heavy rain that fell around Humberside and southern Yorkshire.

All LAM runs valid for 28/0000 predicted a small area of heavy showers over Belgium in the evening (Fig. 5.2.1), coinciding with a maximum 850 hPa θw of 20°C and low level ascent. In reality, the air over Belgium was unstable from the surface (temperatures were as high as 34°C at 1500), and there were isolated thunderstorms here during the late afternoon. (In contrast the air over the UK, in which the MCS developed, had θw values of only 15 to 17°C.)

At 250 hPa, the forecast model winds at 28/0600 (in all runs) were markedly different from reality because of the development of the MCS (Fig. 5.2.2).

5.3 Justification for re-runs

(a) Humidity field

There were large gradients of humidity ahead of the cold front, which at 27/1200 were close to Corunna (Cr on Fig. 5.3.1). The model background was much moister than the radio-sonde sounding (Table 1), although the data fitted the temperature and wind fields very well. The process of assimilation had reduced the moisture in the model too much (for a discussion see Section 5.5). A re-run without the sounding would increase the moisture in the flow and hence should facilitate the formation of showers downstream over north France and the UK.

Table 1

Radio-sonde observations converted to model levels and compared with the LAM background values for 1200 UTC on 12 July 1994 at Corunna (Cr in Fig 5.3.1).

Pressure	Temperature °C		Wind deg/knots		Relative humidity %		
hPa	Obs.	Obs-Bgd	Obs	Bgd	Obs	Obs-Bgd	Bgd
978.2	15.5	-0.5	011/04	026/09	85.4	-8.9	94.3
933.4	14.2	-0.8	357/06	048/04	92.3	19.0	73.3
872.3	14.5	-1.4	306/03	062/01	60.9	22.0	38.9
794.1	12.9	0.3	214/11	214/07	17.9	-14.3	32.2
700.6	6.6	1.0	215/21	217/16	12.8	-34.8	47.6
599.8	-1.7	1.4	215/28	213/24	11.1	-60.9	72.0
504.4	-11.6	-1.0	216/35	216/34	28.1	-28.7	56.8
421.9	-22.0	-0.8	219/43	218/42	34.7	-36.9	71.6
354.5	-29.6	-0.6	220/50	223/51	29.5	-20.2	49.7
299.5	-39.0	-0.5	220/55	225/58	27.7	-19.6	47.3
249.1	-47.8	0.7	221/57	228/64			
198.6	-52.6	0.7	228/61	230/69			

(b) Upper short-wave trough (swt)
It was originally assumed that the model did not produce enough ascent to release the potential instability present in the airmass. From the WV images on the 27th (see for example Figs 5.3.1 and 5.3.2) it is apparent that the upper trough had more detail than in the model. A perturbation in the moisture field labelled T is seen to run northeastwards at 50 knots and become more marked. It is interpreted as a swt which travelled along the forward side of the large-scale trough. The Cb development over Biscay (at A in Fig. 5.3.2) and later the MCS both formed ahead of this swt where increased airmass ascent would be expected. The swt was not apparent in the model and, because of the lack of observations, could not be defined by the model analyses.

(c) Jet streak
Again using the WV imagery, a deformation zone (DD' in Fig. 5.3.1) was identified in the relative flow and the possible location of a jet streak proposed on the forward side of the swt. (NB: the moisture boundaries give the direction of the relative flow at the level of the boundary.)

Aircraft winds (85 knots reported at 287 hPa) around 47°N 8°W were 10 knots stronger than the model background. The radio-sonde winds from Corunna and Brest (Cr an Br in Fig. 5.3.1), showed that the maximum wind was at a higher level, at around 230 hPa and just over 100 knots. The LAM analysis was closer than the background to the aircraft winds but still lacked the maximum speed of the jet streak on the forward side of the swt.

5.4 Model re-runs and Results

Experiment 1: Effect of modifying humidity
The LAM was re-run without the Corunna humidity data. The effect on the 500 hPa RH analysis field was quite dramatic (Fig. 5.4.1), both in the analysis and the forecast. In the analysis, the frontal zone now had higher values of humidity over Biscay. In the forecast, these higher humidities were advected towards southeast England. The effect at other levels was less pronounced.

The result in the forecast (Fig. 5.4.2) was a band of showers, starting at Brest at 27/1800, and developing more widely along a line oriented 190/010 deg. These showers were more or less in the right area, although the rainfall totals were not large enough. By 28/0600 the band of showers lay over E Anglia to the North Sea and there was a suggestion of a comma-type signature in the layered cloud indicating a circulation in the relative flow (Fig. 5.4.3b). This circulation was more in line with the circulation apparent in the cloud associated with the MCS. In the control run, although there was a small area of cloud, there were no showers and the comma shape in the cloud was absent (Fig. 5.4.3a).

The increased humidity in this experiment meant that with ascent the air became saturated earlier and the resulting latent heat release increased the vertical velocity further. This modified the model profiles (Fig. 5.4.4a,b - note the differences at G and J and H - all above 700 hPa) and released the potential instability (most noticeable at J). Over Jersey (49°N 02°W) at 28/0000 the air was rising at about 16 hPa/h compared to 10 hPa/h in the control run. Taking into account the horizontal wind, this

air was now rising up a slope of 1:300 (similar to a warm conveyor belt) and producing the layered cloud mentioned earlier. A trajectory calculation at 700 hPa locates this air in the Bay of Biscay at 27/1200, between the model soundings P and Q in Fig. 5.4.5. (Q reveals potentially unstable air which was present in the 27/1200 model soundings in both the control and experimental runs.)

Just leaving out the critical Corunna ascent thus radically improved the forecast from the operational 27/1200 LAM run. In the previous two runs, the moist air had been further to the west and the dry air observed in the previous Corunna sounding agreed with the model background and so had no drying effect.

Experiment 2: Effect of modifying winds and humidity

In this re-run an attempt was made to capture the swt and the jetstreak by inserting additional winds over Biscay and slightly sharpening the thermal trough, again omitting the relative humidities from the Corunna sounding (see Annex). Slight initial changes seen, e.g. in the vertical velocity fields, were quickly eliminated in the forecast and the results were very similar to Experiment 1.

Experiments 1 & 2 identified that the main problem in the LAM forecast from 27/1200 arose because the humidity in the model background field was too high near Corunna. The assimilation of the Corunna radio-sonde observation reduced the moisture in the model over too wide an area and prevented showers developing downstream during the night.

5.5 Discussion and future work

Humidity observations

If at some verifying time the model forecast is incorrect, the fault lies either in the model characteristics or in the analysis fields. When the model's winds and temperatures agree with the available observations (e.g. from aircraft), the humidity analysis may be the problem. Obviously, increasing the humidity at the analysis time will inevitably lead to more precipitation in the forecast. Obtaining accurate humidity observations is difficult, though some progress has been made using locally processed satellite data (e.g. GLOSS). Use of integrated water vapour data may also be a way forward.

Assimilation

(a) In these Spanish Plume cases, some of which have large humidity gradients ahead of the upper trough, the relative positions of the features in the model and the observations can be critical. The radio-sonde sounding at 27/1200 for Corunna was much drier than the model background and the resulting assimilation dried out a critical area to the north and northwest of the station. When assimilating radio-sonde humidities, the difference between the observation and the model background (increment) is at present applied equally in all directions, ie the area of influence is a circle; however, the greatest changes in humidity usually lie at right angles to the windflow so it would be more realistic if the increments were applied more along the airflow - i.e. the area of influence became a rather narrow ellipse.

(b) The LAM tends to run moister than the real atmosphere (in order to produce the

correct precipitation), so in critical cases the real observations may dry out the model too much. The recent humidity modification (Bell 1994) only raises the observed radio-sonde humidities when they are above 80%. It may be necessary to raise observed radio-sonde humidity values in the middle and not just the upper range of humidities.

(c) Although the LAM can resolve features on the jet streak scale, say 300 km, such small-scale features are difficult to insert into the model. It would be easier on a finer grid and this is a further reason for extending the MES grid to cover the area to the south and southwest of the UK.

Modelling major convection

The LAM is not able to model the processes within an MCS and hence would not be able to predict the subsequent effects. No doubt the latent heat release and subsequent warming as the MCS developed distorted the upper flow. This is clearly illustrated in this case study. There was a very sharp 500 hPa trough over the E Midlands at 28/1200 which was not forecast in the control run (Fig. 5.2.2). The differences are highlighted by the winds observed at Boulmer (Bo in Fig. 5.3.1). Here, the maximum wind was 94 knots at 28/0000. At this time the forecast from 27/1200 had 60 knots; that from 27/0000 had 50 knots. The LAM analysis at 28/0000 LAM had 95 knots.

Forecasting the convection

The MCS developed at the western edge of the warm, moist, potentially unstable air which was already over the Bay of Biscay at 27/1200. There was a fine balance between the development of this potential instability and its subsequent release during ascent. If a sequence of model soundings (or instability indices) had been available from the Biscay area, they might have alerted forecasters to the threat.

At 27/1500 thunderstorms developed over Biscay. These were studied by Browning and Roberts (1994) and they used WV imagery to locate areas of development and relate these thunderstorms to over-running dry air. The relationship between the Cb development and the edge of the dark (dry) slot in the WV image can clearly be seen in the sequence shown in Fig. 5.1.4. This is for the later storms that developed into an MCS. In the model, the upper level dry, low θw air to the west of the front was approaching and there was a marked humidity gradient, increasing with time, at 500 hPa (Fig. 5.4.1a). However the dry air did not overrun and as the LAM did not capture the development of the swt (and associated positive vorticity advection), the ascent was probably too small and hence the showers produced were light even in the re-runs.

Cloud motion winds

A further aspect of this case: The anvil cirrus of the thunderstorms that developed at 27/1500 over Biscay was carried north towards southwest England over the next 3 to 8 hours before dissipating (Fig. 5.3.2). This Cb cloud development resulted in a bad cloud track wind (CTW) at 27/1800 which had a 35 knots vector difference from the background field. Although the cirrus cloud was streaming away to the north, the CTW was presumably calculated on the movement of the southern end of the cloud pattern, where new cells were developing. This cloud edge was moving with some mid-level flow at 200/29 knots. This wind was wrongly assigned to the cirrus levels

at 290 hPa where the background wind was 220/59 knots. The CTW was rejected in the quality control but this example highlights one of the problems in calculating CTWs.

6. Recommendations

The authors' recommendations were presented at the Workshop but they are here supplemented by suggestions from attendees at the morning session and from the floor in the afternoon plenary session as well as some that emerged from subsequent discussions.

6.1 For Forecasters

(a) Water vapour (WV) imagery is very useful in 'Spanish Plume' situations, particularly with regard to monitoring the NWP guidance.

(i) Patterns on WV imagery can help identify the horizontal distribution of moisture, locations of short-wave troughs and cyclogenesis. WV has an advantage over IR because information is available from cloud-free air.

(ii) It is useful to compare the position of dry zones in WV imagery with positive PV anomalies from the model (see Mansfield 1994). If there is a mismatch, an allowance can be made when interpreting the numerical forecast either subjectively or perhaps by inserting extra data into the model.

(iii) Gary Ellrod (1990) has established a relationship between dry air over-running very warm, potentially unstable air and thunderstorm development in the USA. The process resembles the split front model and needs to be understood further before it can be used operationally. Even now, it can alert the forecaster to the possibility of convective development.

(b) It would be useful if operational forecasters could see a T+0 LAM analysis prior to intervention and compare it with the model background field to see, in critical areas, the effect of assimilating the observations.

(c) Model soundings from areas selected by the forecaster would help in assessing the likelihood of convective development.

(d) Model stability charts, output at 6 hourly intervals, could alert the forecaster to areas of increasing medium level instability, before the model produced precipitation or even if the model produced none. In those areas a trajectory analysis would allow him to see where the air had originated so he could check the details of the airflow.

(e) Appropriate diagnostics, for example fields of vorticity and vertical motion, would help the forecaster see what lies behind some of the model's output. In unstable situations it would be useful to know, in certain areas, how close the

model is to convection. Also for critically placed ascents like Corunna, quick access to the differences from background would be helpful.

(f) Diagnostics could also include airflow trajectories to show where air of different origins is coming together at different levels and so changing the stability. Once a system is identified (e.g. trough or comma cloud) system-relative winds would be useful.

(g) ATD (sferic) charts are helpful, particularly for locating the initial storm location.

(h) It may be useful to take account of French model products in these situations.

6.2 For Observations

For forecasting 12 - 24 hours ahead in 'Spanish Plume' situations, key areas are the flow on the forward side of the upper trough over the Bay of Biscay and western France where there are few conventional observations to resolve horizontal and vertical gradients in humidity and upper wind on small enough scales. These features may be seen, for example, on WV imagery. (The same problem of lack of observations in these crucial areas was highlighted by Morris and Gadd (1988) in the case of the Great Storm of 1987.)

(a) For currently available observations, consideration should be given to:

(i) collecting and using all available data from surface and upper air platforms.

(ii) deploying more buoys in the Biscay area (though these would probably not provide significant positve impact in the cases studied here).

(iii) trying to obtain more aircraft data over the Biscay area.

(b) With regard to the future:

(i) use should be made of any wind profiler data over France and Iberia.

(ii) it would help if there were a denser network of French radio-sondes, with more frequent observations.

(iii) resources must be put into looking into the impact on NWP models of new satellite data, e.g.:

WV winds from METEOSAT,

locally retrieved upper tropospheric humidity values from the polar orbiting satellites via GLOSS,

Special Sensor Microwave Imager (SSM/I) data such as integrated water vapour.

(iv) the idea of sending unmanned airborne vehicles (UAVs) to key areas should be considered.

6.3 For Modellers: assimilation/ model development

(a) The MES should be extended further south over western France and Iberia. The cases considered here might constitute a good trial.

(b) Assimilation of humidities (and perhaps some other variables) might be more effective if the radius of influence could be extended along the windflow (i.e. in an ellipse) rather than the present circle. (In reality the ribbons of high and low humidities are shaped by the windflow relative to the system rather then the actual winds but this refinement would be too time-consuming to apply and probably not cost-effective except in individual case studies.)

(c) Increasing observed radio-sonde humidities below 80% should be considered because the model tends to run moister than the real atmosphere.

(d) Assimilation routines should be prepared for new data from satellites such as integrated water vapour.

(e) Consideration should be given to:

(i) reducing the weight and/or area of influence given to isolated radio-sonde ascents (e.g. Corunna and Brest) which may not be representative of fairly narrow zones of moist air at mid-levels.

(ii) putting more weight on CMWs, and (the few) AIREPS to locate the upper short wave features.

(iii) adjusting the quality control of CMWs in very unstable conditions.

(f) The LAM does not have the capability to produce the organisation of atmospheric processes within MCSs. Some parametrization could be considered involving depth of convection, convectively available potential energy and windshear to enable it to predict MCSs. The MES, with its higher resolution, may be able to incorporate some feedback between the variables at gridpoints to simulate an MCS.

(g) Alternative presentation of the MES products is needed, in consultation with the forecasters. For example, some idea of depth of convection would be helpful. If no shower symbols are produced in a potentially unstable airmass, it would be helpful to see how close the model is to producing convection. Fields of vertical motion would also be useful.

7. Acknowledgements

Julian Heming who compiled the model runs. Also to Bruce Ingleby, Gary Holpin, Peter Newcomb, Paul Taylor, Simon Anderson and Richard Graham for their contributions. Ewen McCallum for helpful discussions.

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Annex - Input to the LAM re-runs.

Extra simulated observations inserted in re-runs (latitude and longitude of locations followed by levels in hPa and relative humidities in %).

12 July 1994 1200 (Annex Map 1)
Trial 1 - with extra humidity data over Biscay:

49N 7W, 47.5N 8W, 46N 9.5W:
900 95, 800 50, 700 80, 600 90, 500 90.
44.5N 4W, 45N 7W, 44N 9W, 43N 11W, 41.5N 10.5W:
900 100, 800 50, 700 80, 600 80, 500 70.
49N 10W, 47.5N 12W, 45.5N 13W, 43.5N 14W:
900 80, 800 80, 700 30, 600 50, 500 50.
46.5N 5.5W:
900 95, 800 70, 700 80, 600 80, 500 60.

Trial 2 - just omitted relative humidity data from Corunna and Brest (stations 08001 and 07110)

Trial 3 - Extra relative humidity data (%) from GLOSS
Time 12/0537 UTC:

Lat(N)/long(W)	700 hPa	500 hPa	400 hPa	300 hPa
47.3 3.9	43	10	15	20
45.8 1.6	75	10	16	31
44.0 2.7	51	8	15	37
46.3 5.1	27	9	14	17
44.3 4.7	20	5	9	32
44.7 4.9	21	5	9	27
44.5 2.9	37	6	11	29
45.8 3.8	51	8	13	24

Time 12/0757 UTC:

Lat(N)/long(W)	700 hPa	500 hPa	400 hPa	300 hPa
44.8 1.0	60	8	17	34
45.3 1.5	77	10	19	44
46.6 3.2	83	9	11	18
45.3 5.2	24	8	14	29
45.5 3.6	36	6	10	26
46.8 5.2	22	12	23	32

27 July 1994 1200 (Annex Map 2)
Experiment 1 - to check humidity assimilation :
Omitted RH at Corunna (station 08001)

Experiment 2 - to try to insert swt and jet streak :
230 hPa 46N 08W 200/105knots
230 hPa 44N 11W 200/50knots
230 hPa 42N 15W 200/60knots
230 hPa 46N 05W 200/60knots
Thickness 45N 9.5W 5580m
45N 15W 5580m
Omitted RH at Corunna (station 08001)

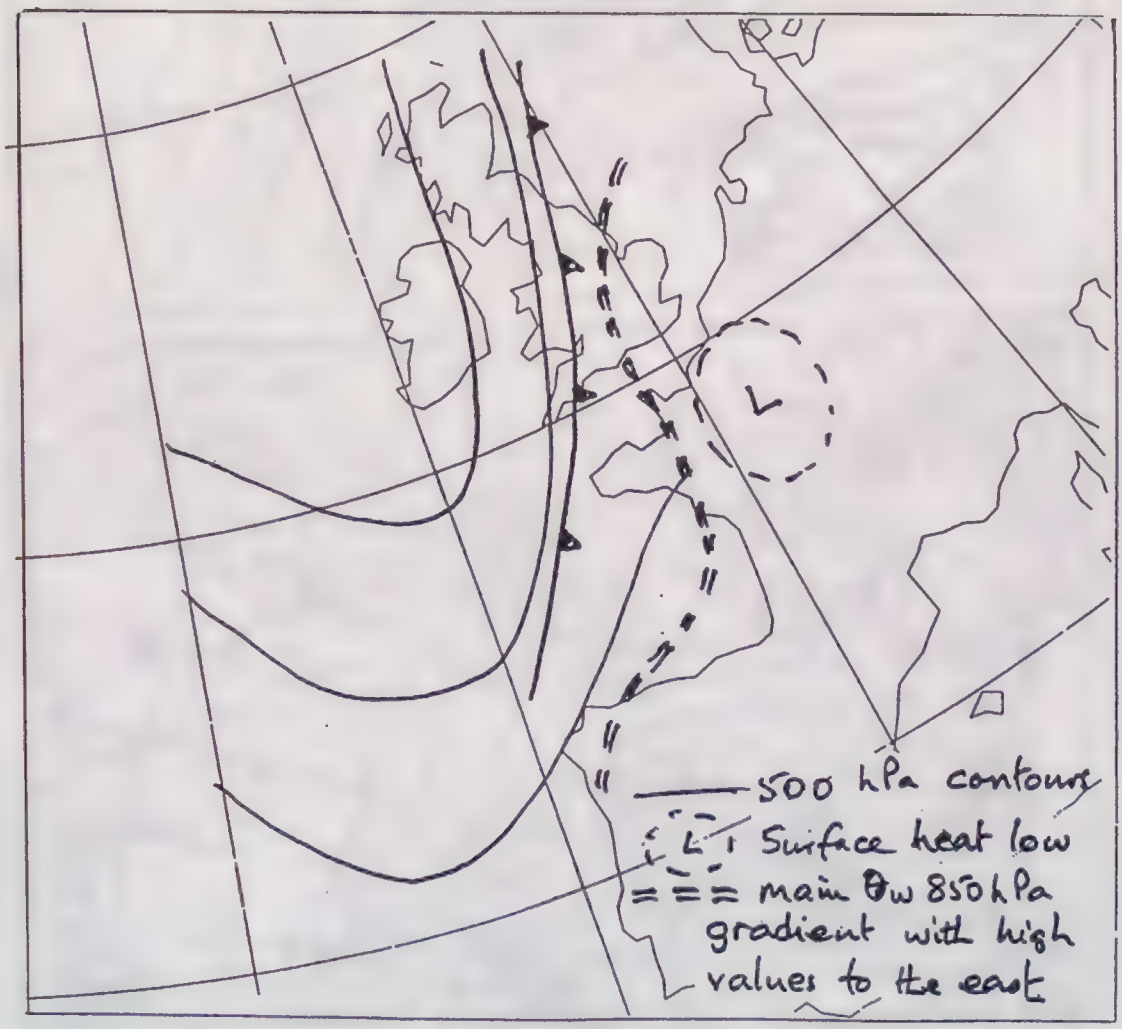


Fig. 1.1 Schematic diagram of synoptic components of the "Spanish Plume".

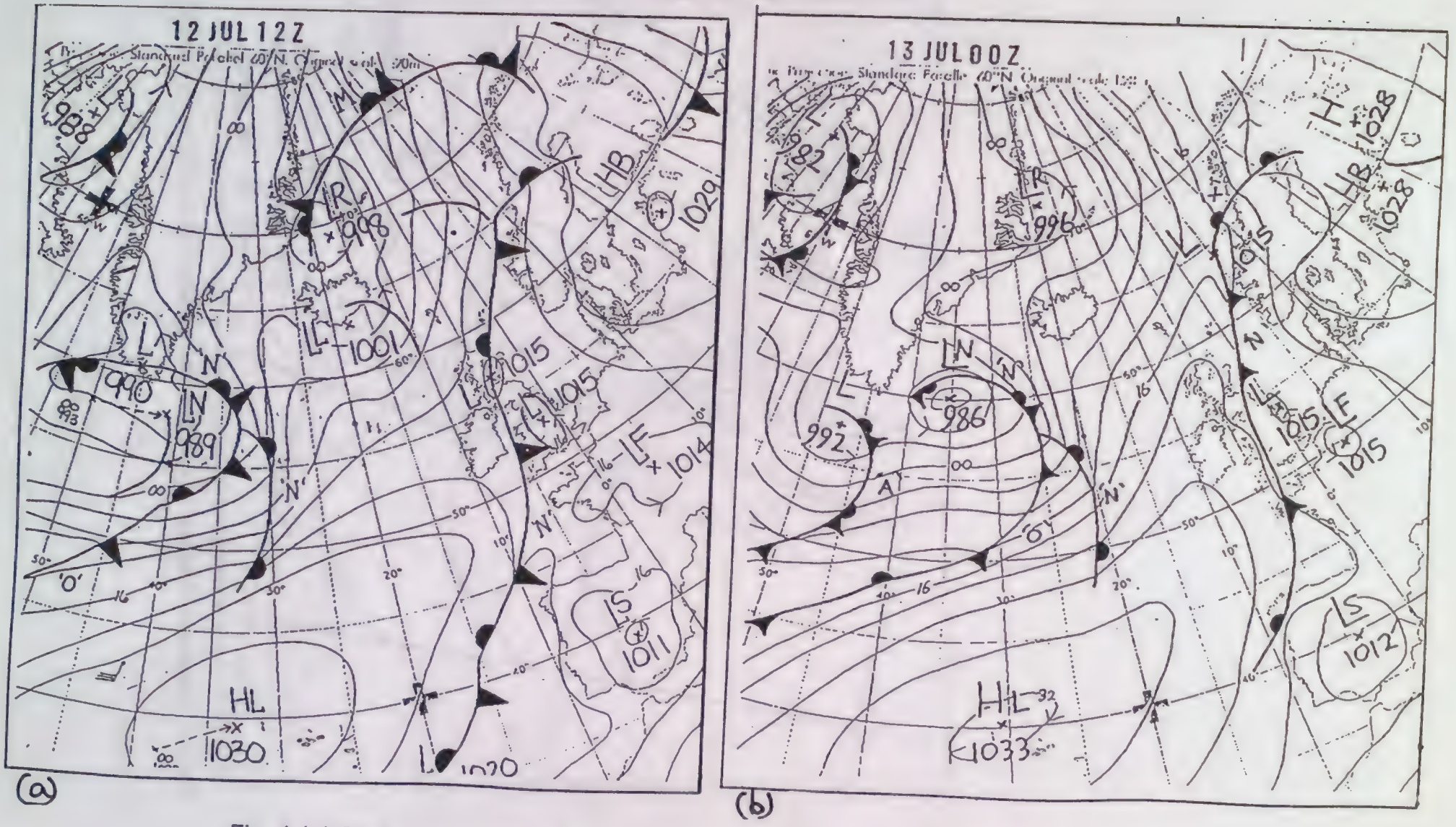


Fig. 4.1.1 Surface analyses on (a) 12 July 1994 at 1200, (b) 13 July 1994 at 0000.

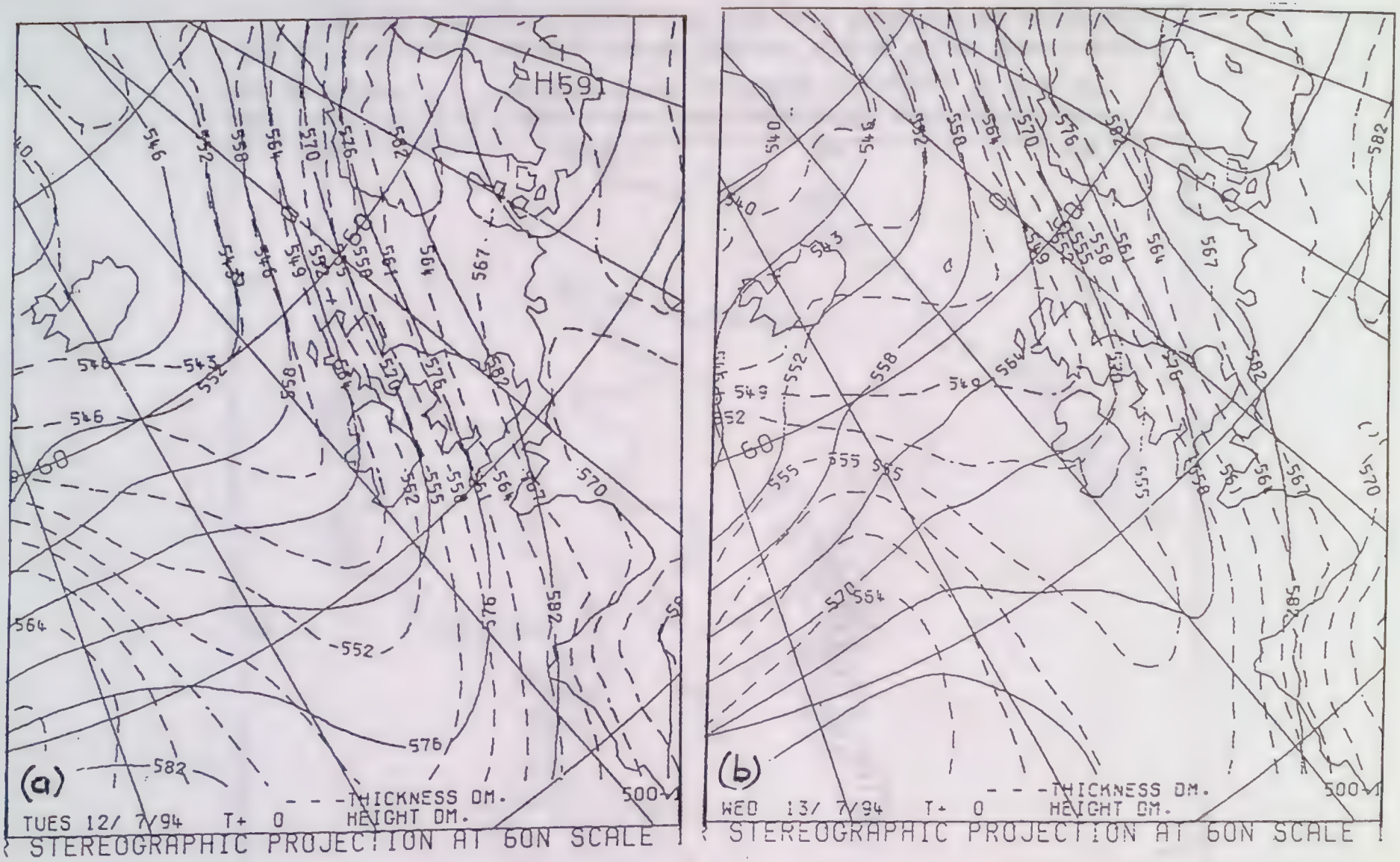


Fig. 4.1.2 LAM 500 hPa and thickness analyses on (a) 12 July 1994 at 1200, (b) 13 July 1994 at 0000. Dashed lines are 1000 to 500 hPa thickness in dam.

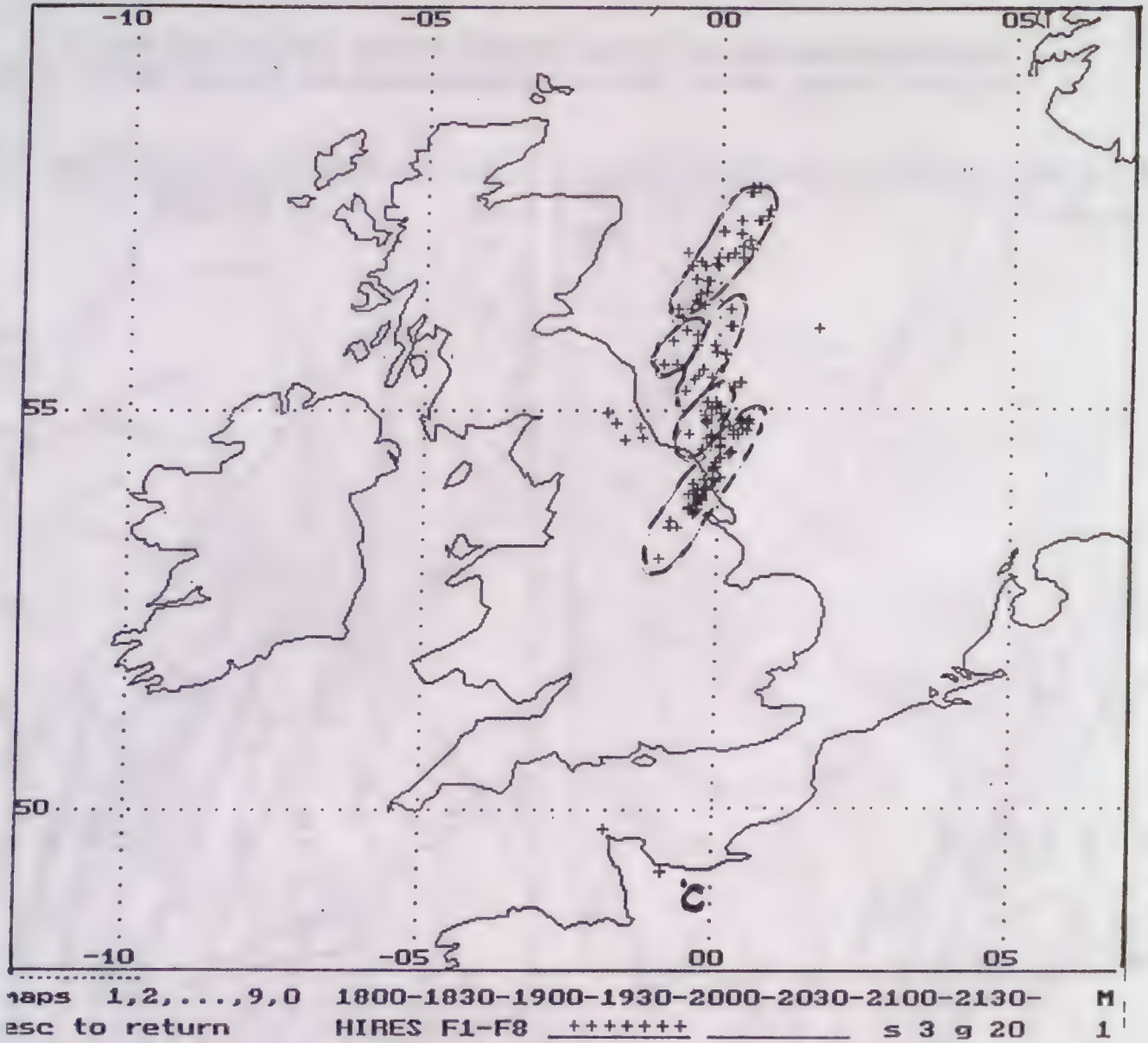


Fig. 4.1.3 Positions of lightning between 1800 and 2130 on 12 July 1994. Dashed lines enclose areas of lightning from one storm. Notice the two reports near Caen (C), at 2100 and 2130.

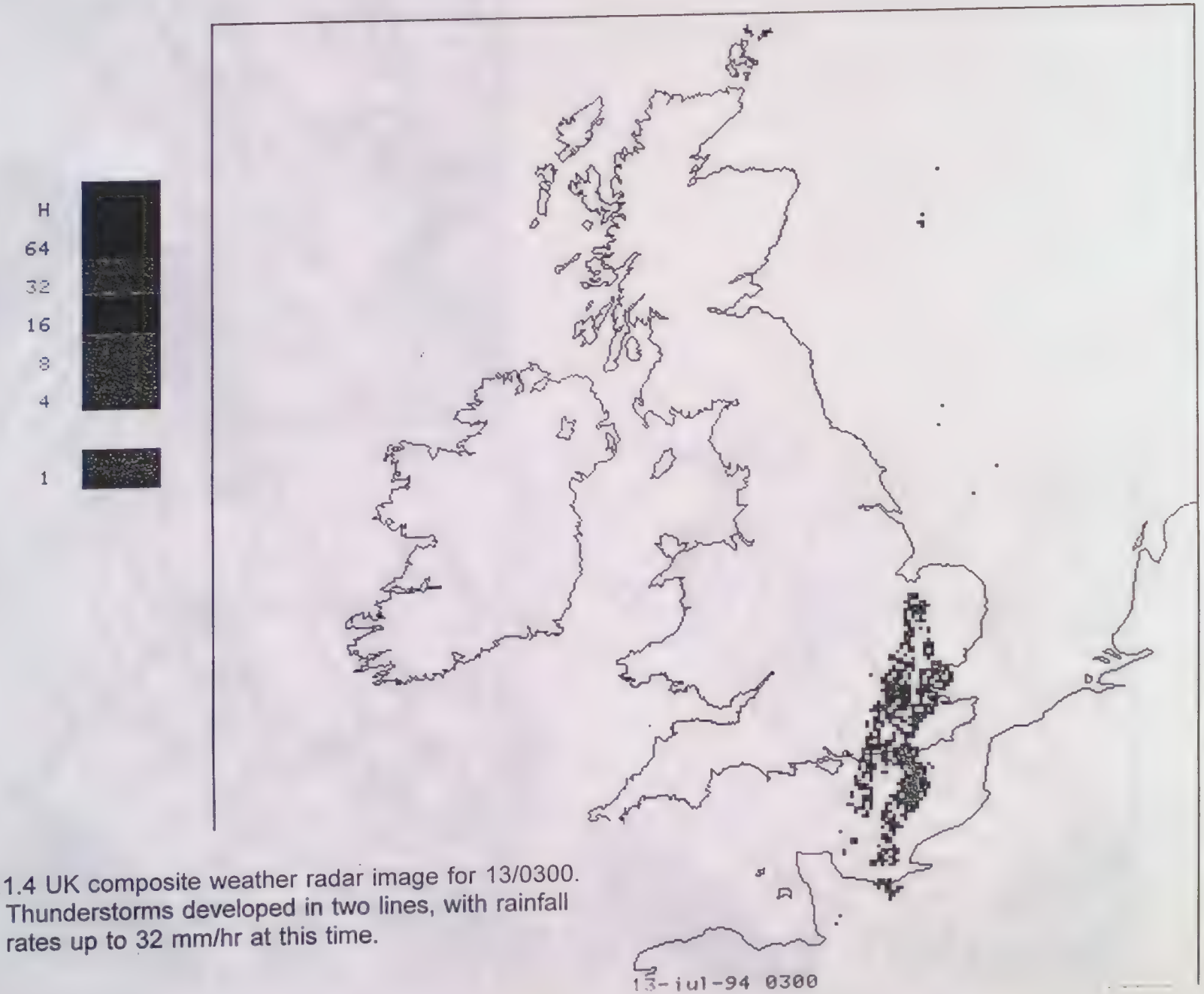


Fig. 4.1.4 UK composite weather radar image for 13/0300. Thunderstorms developed in two lines, with rainfall rates up to 32 mm/hr at this time.

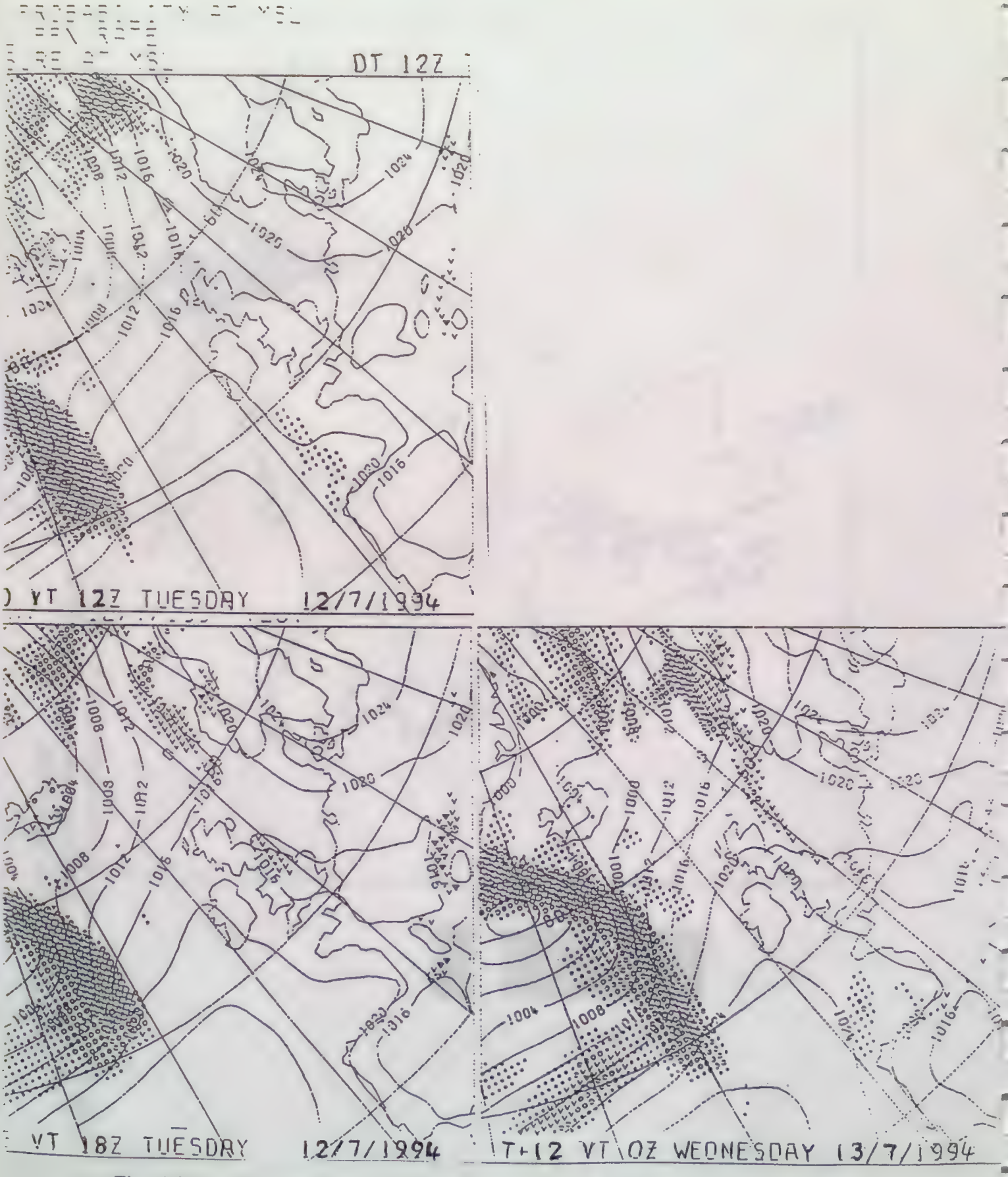


Fig. 4.2.1 LAM operational forecast from 12/1200; T+0, T+06, T+12. This shows showers over northeast England but no showers in the southeast. The lines are MSL pressure. The dots and circles are rain and the Vs represent showers - the larger, the heavier.

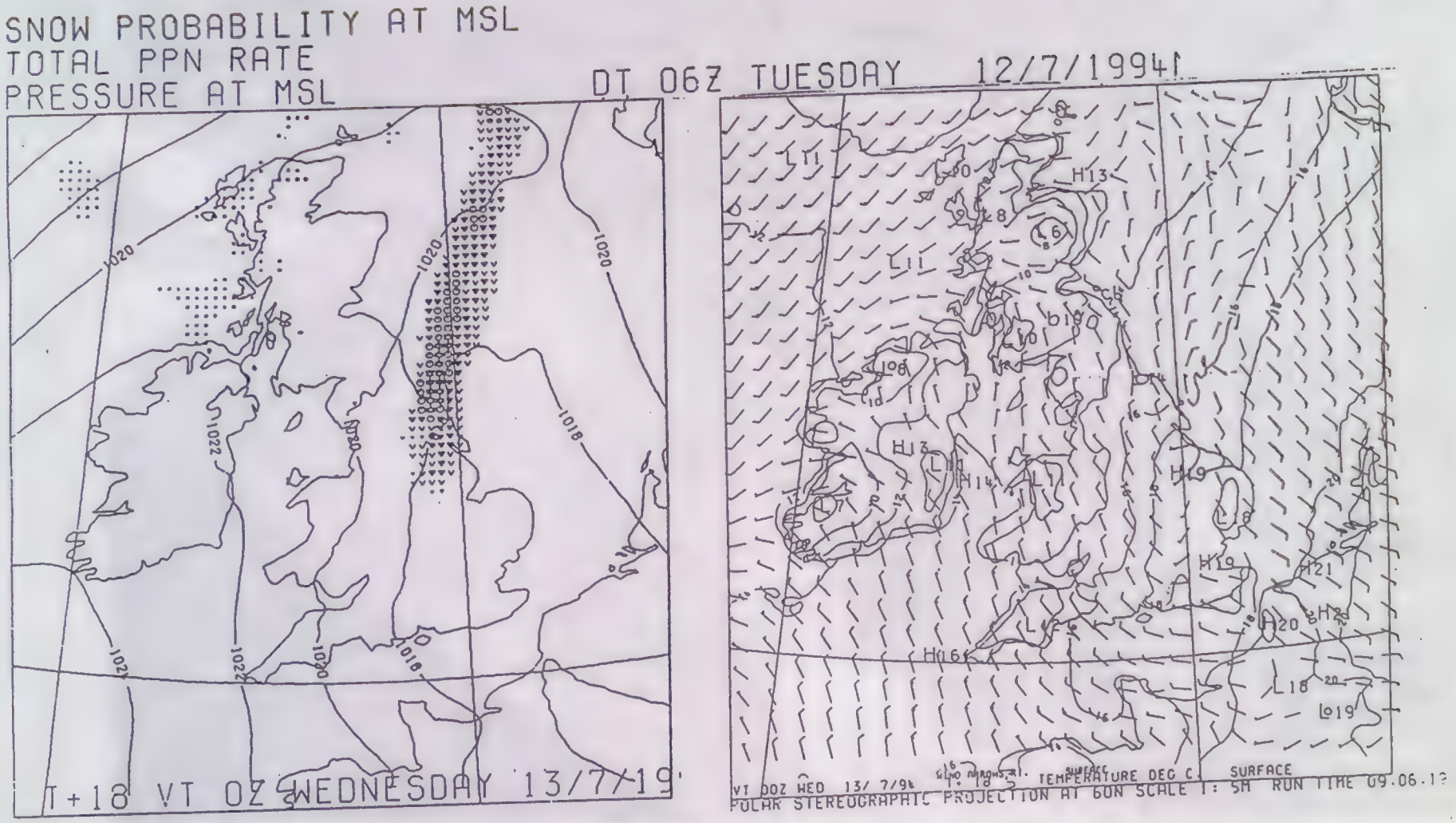


Fig. 4.2.2 MES forecast, data time 12/0600 and valid at 13/0000, showing (a) MSL pressure and precipitation, (b) surface temperature field and troughing over eastern England in the surface winds.

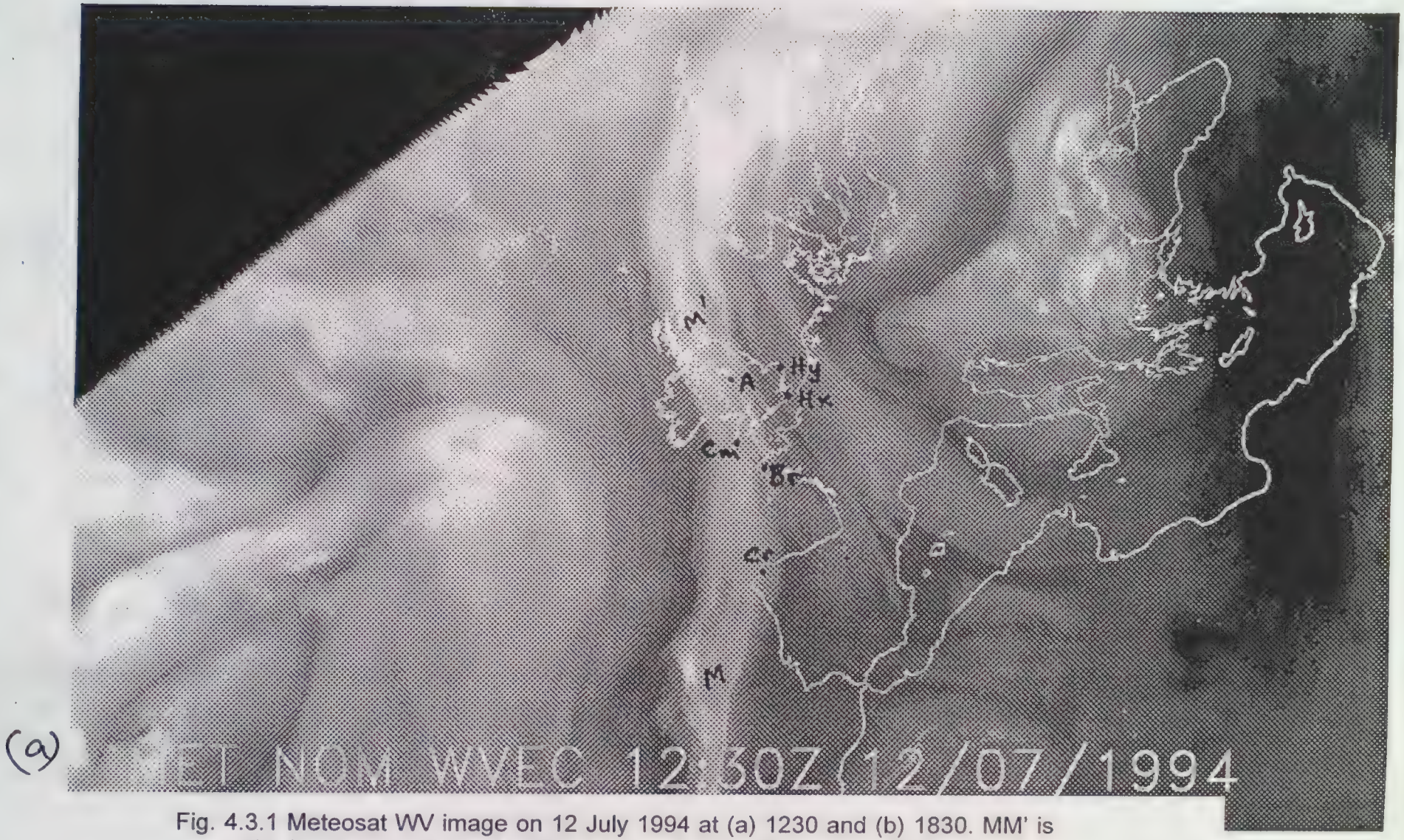


Fig. 4.3.1 Meteosat WV image on 12 July 1994 at (a) 1230 and (b) 1830. MM' is the band of upper level moisture associated with the front. Station locations: A Aughton, Hy Hemsby, Cm Camborne, Hx Herstmonceux, Br Brest, Cr Corunna.

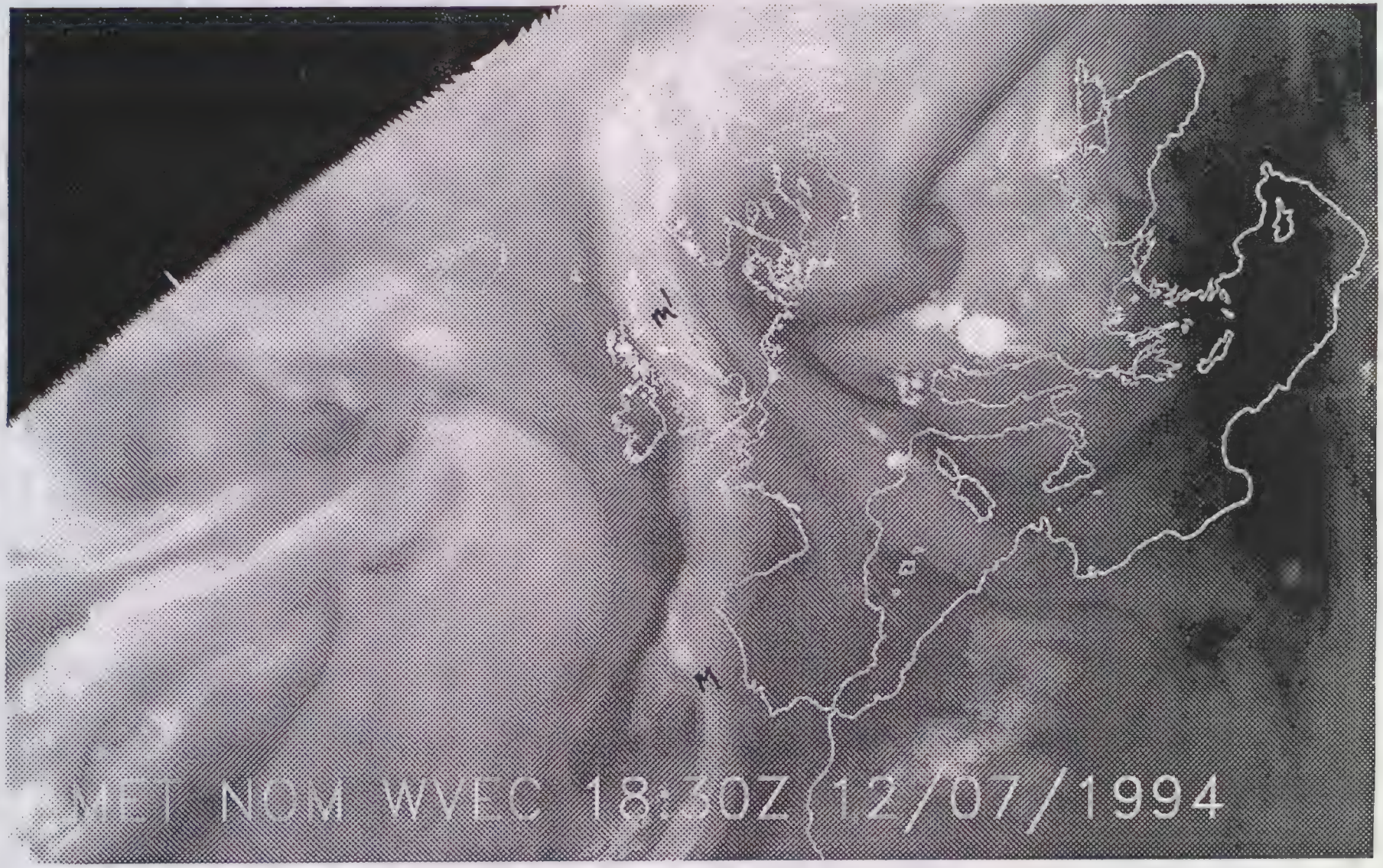


Fig 4.3.1 (b)

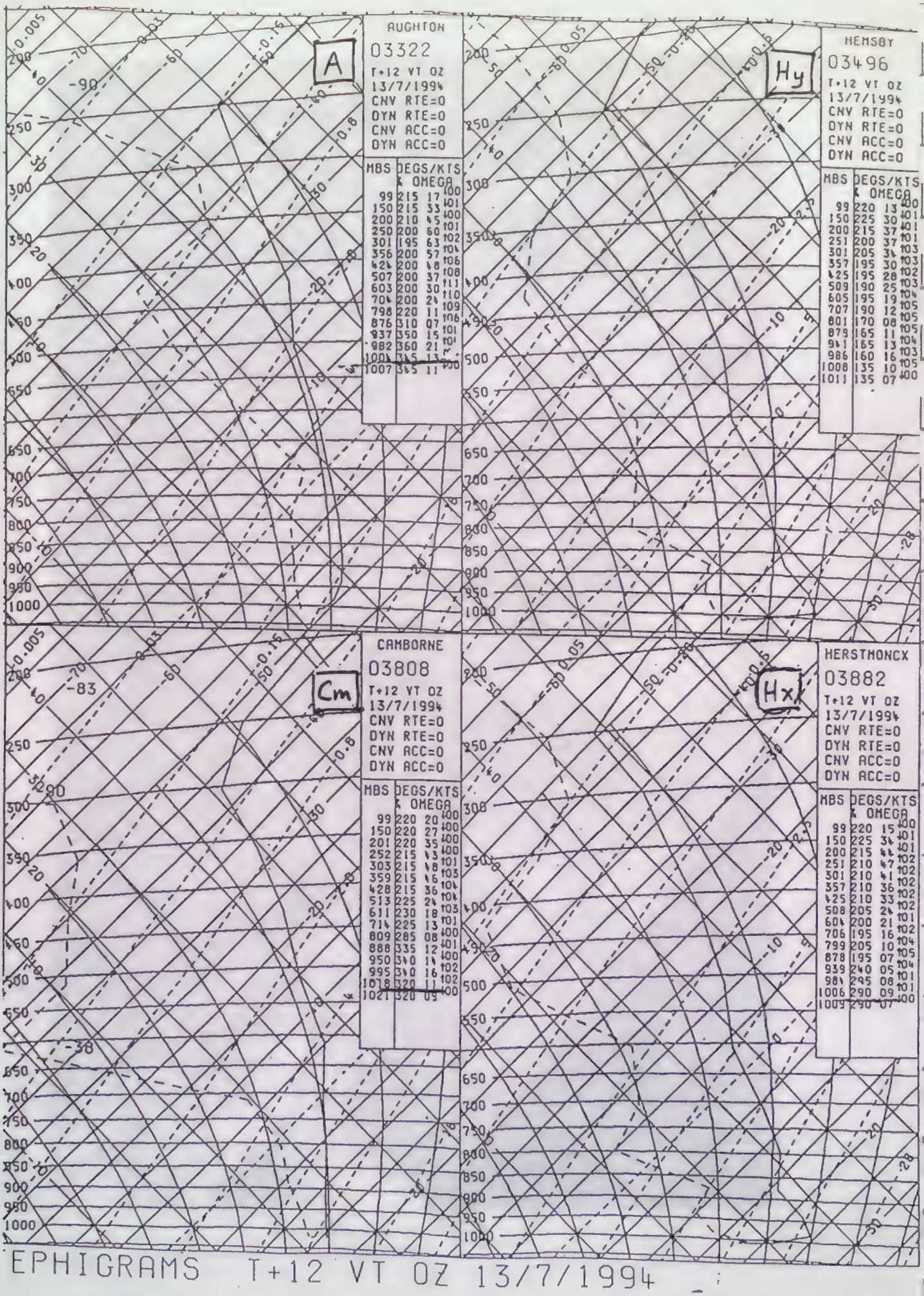


Fig. 4.3.2 Model soundings for the southern UK from the LAM operational run at 12/1200 valid for 13/0000. Station locations are shown in Fig. 4.3.1

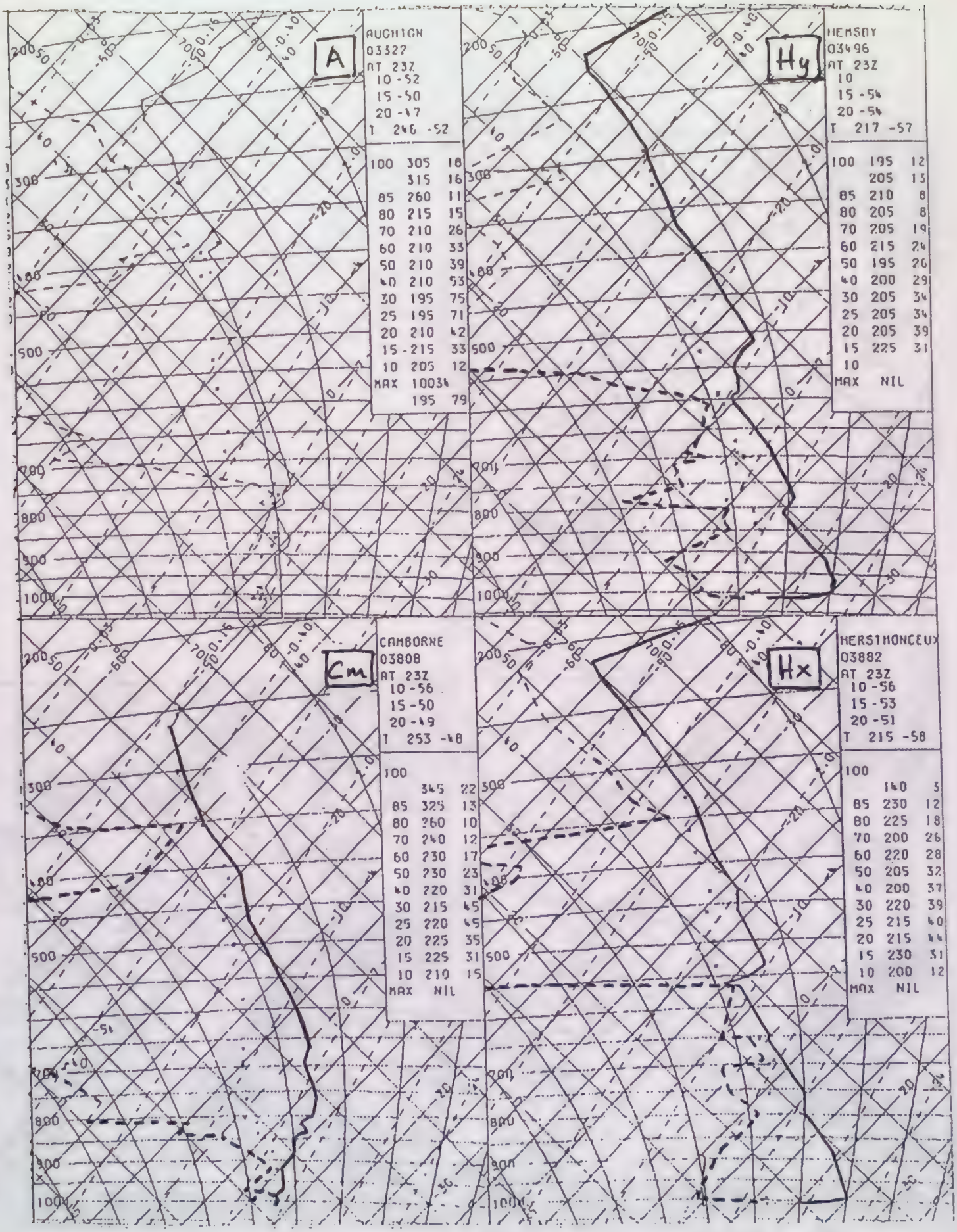


Fig. 4.3.3 Actual soundings at 13/0000 showing the pre-storm profile at Hx and the start of moistening at Hy. At this time, thunderstorms were 100 km to the southwest of Hx.

Fig. 4.4.1 LAM forecast from Trial 1, run with extra humidity over Biscay (see Annex for details) from data time 12/1200 valid for T+0, T+6, T+12. Comparison with Fig. 4.2.1 shows the extra showers over northern France and southern England at midnight.

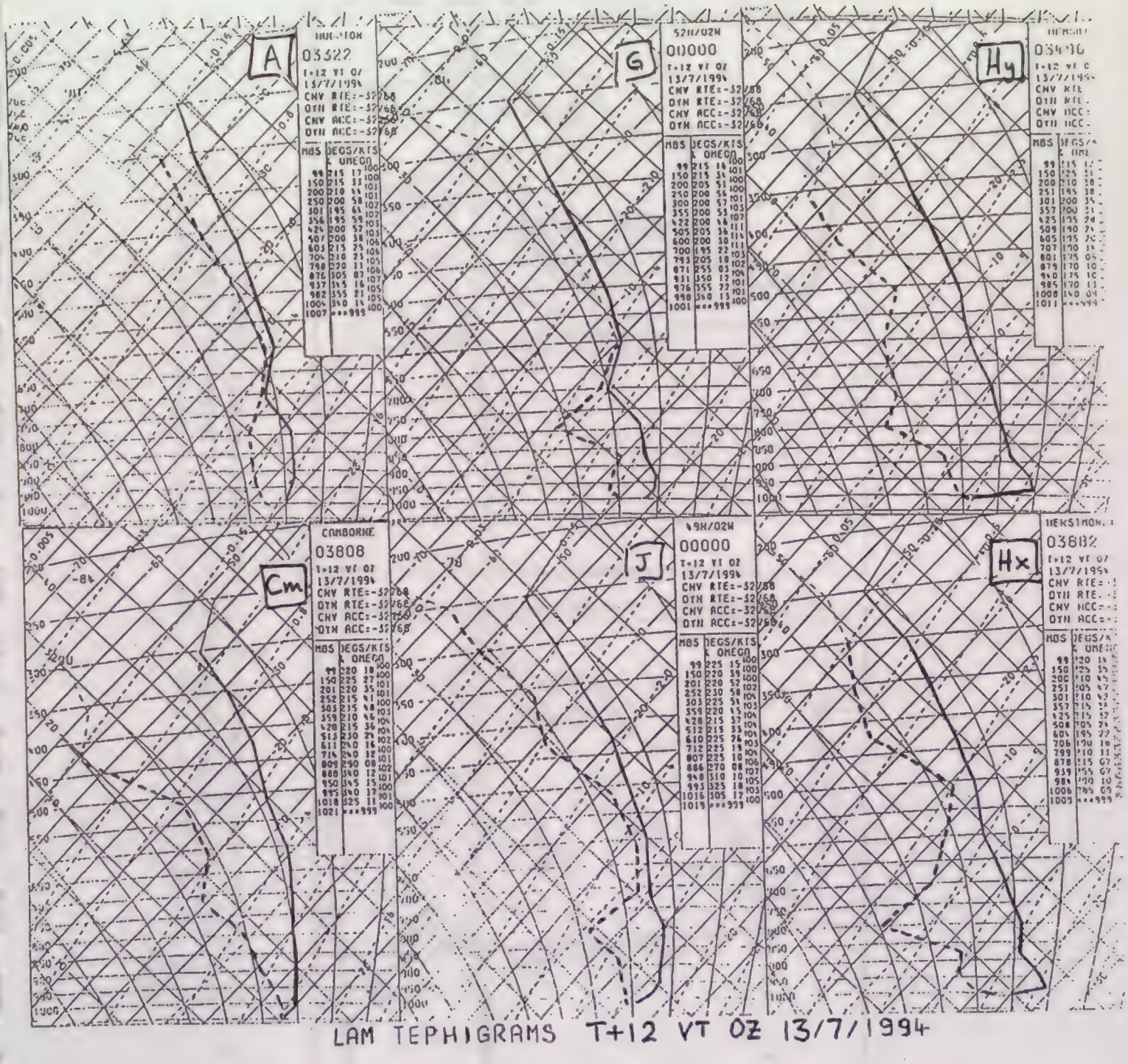


Fig. 4.4.2 Model soundings from Trial 1 valid at 13/0000 showing slightly increased moisture over southeast England (at Hx) and profiles associated with the showers (at J and G) located in Fig. 4.4.1a).

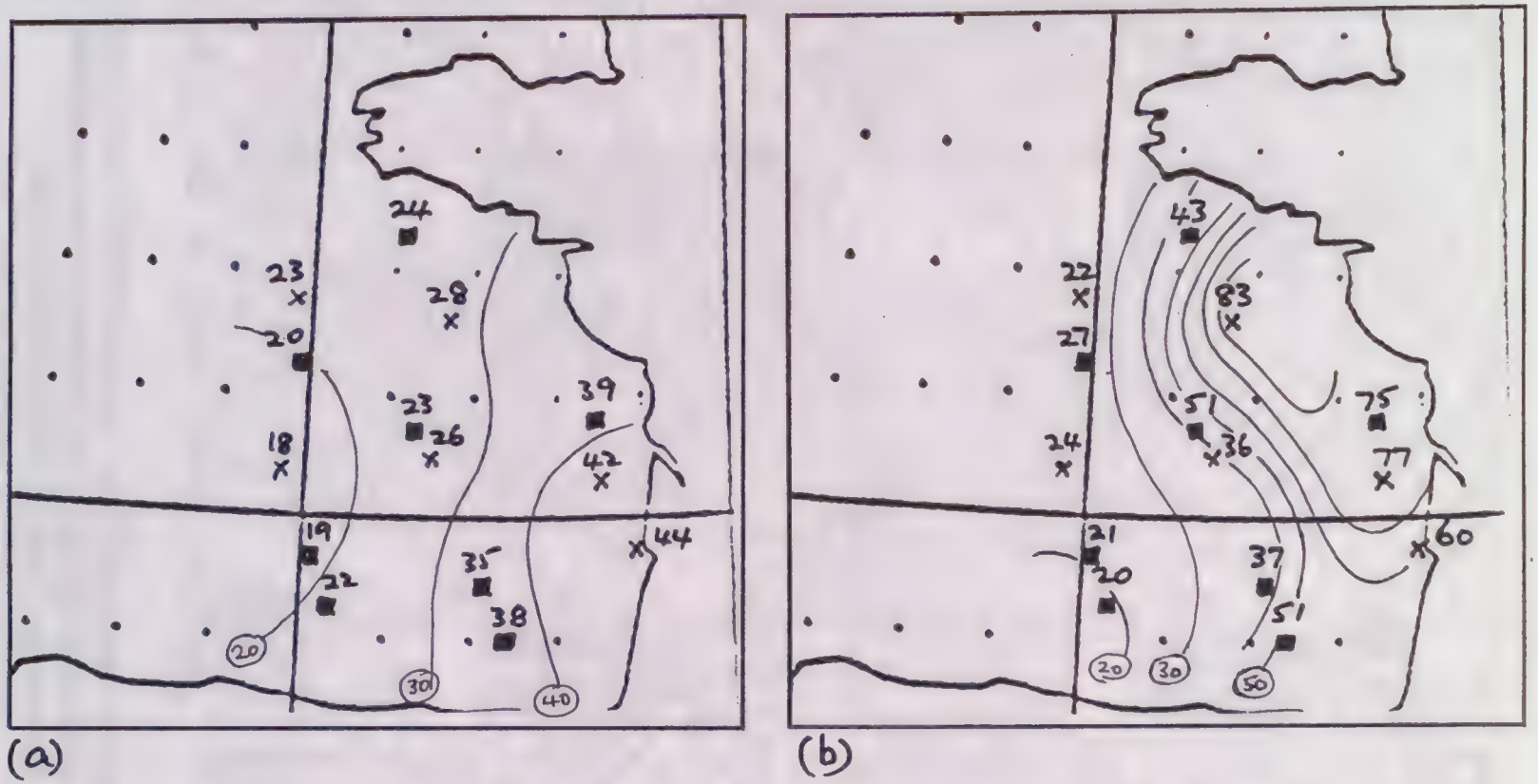


Fig. 4.4.3 Relative humidities at 700 hPa (a) LAM background at 12/0600, (b) hand analysis of GLOSS data at 0537 and 0757. (Observation times are indicated: ■ = 0537, X = 0757.) Notice the large difference over northeast Biscay.

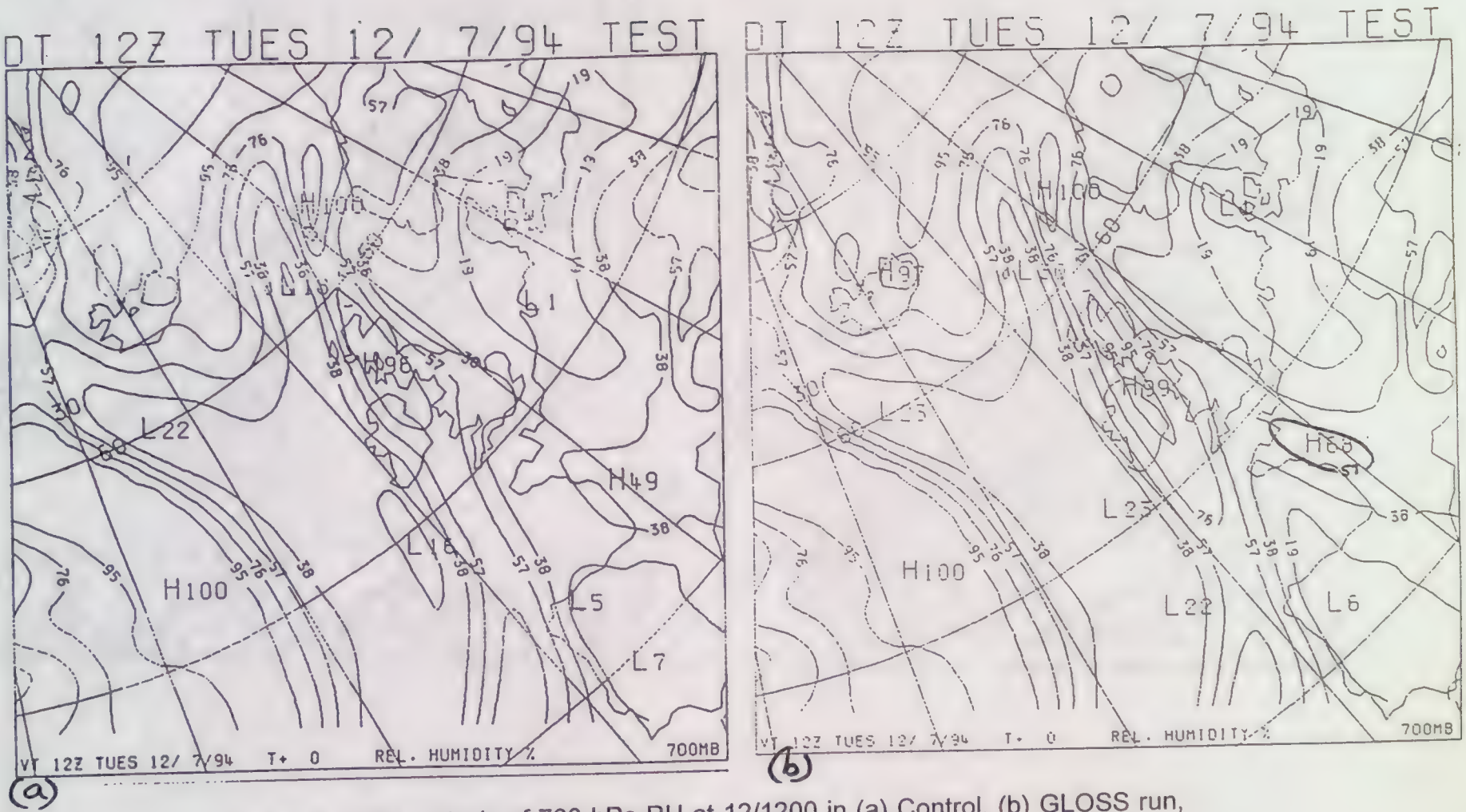


Fig. 4.4.4 LAM analysis of 700 hPa RH at 12/1200 in (a) Control, (b) GLOSS run, showing high values over northern France .

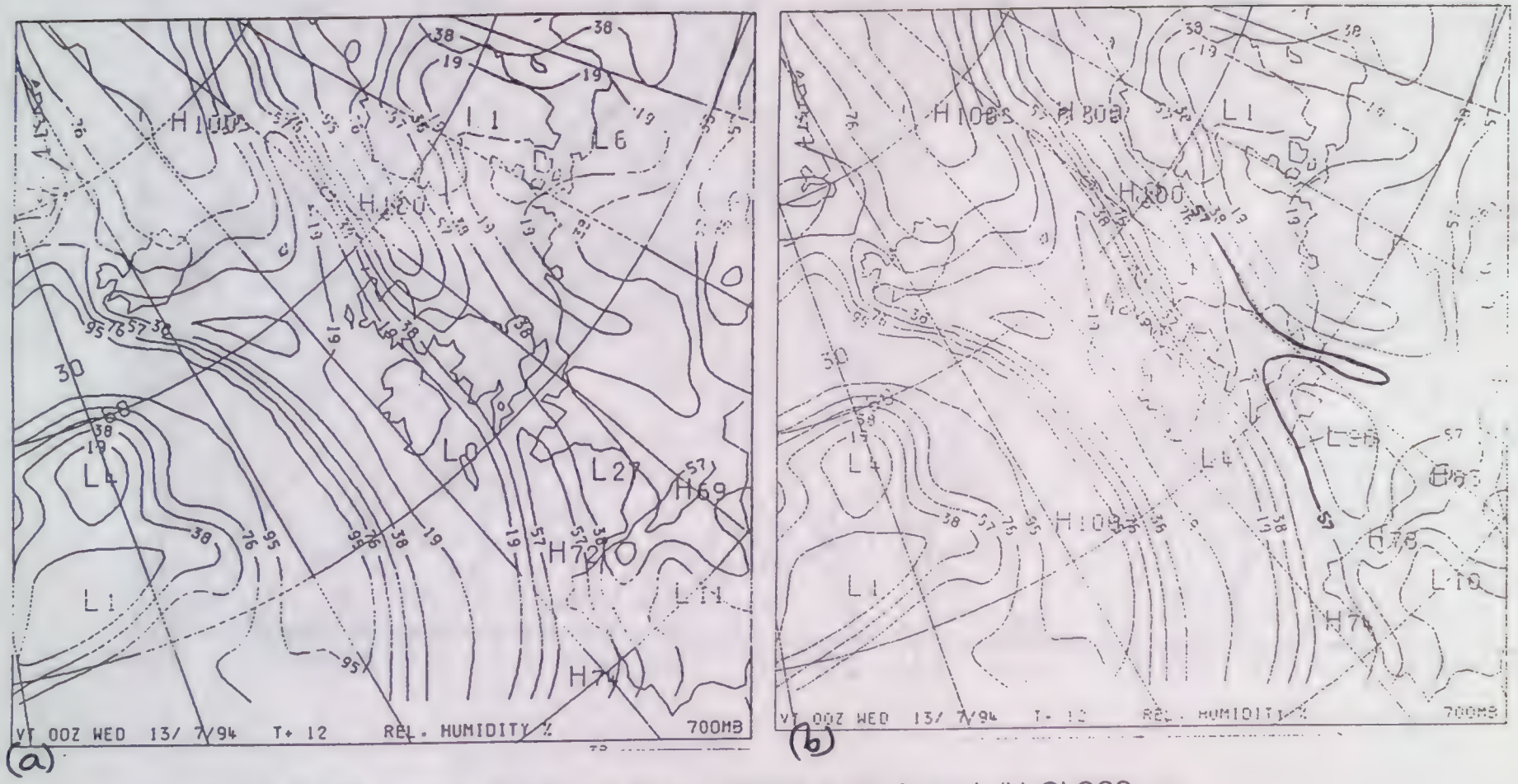


Fig. 4.4.5 LAM forecast of 700 hPa RH for 13/0000 in (a) Control, (b) GLOSS run, showing high values over southeast England.

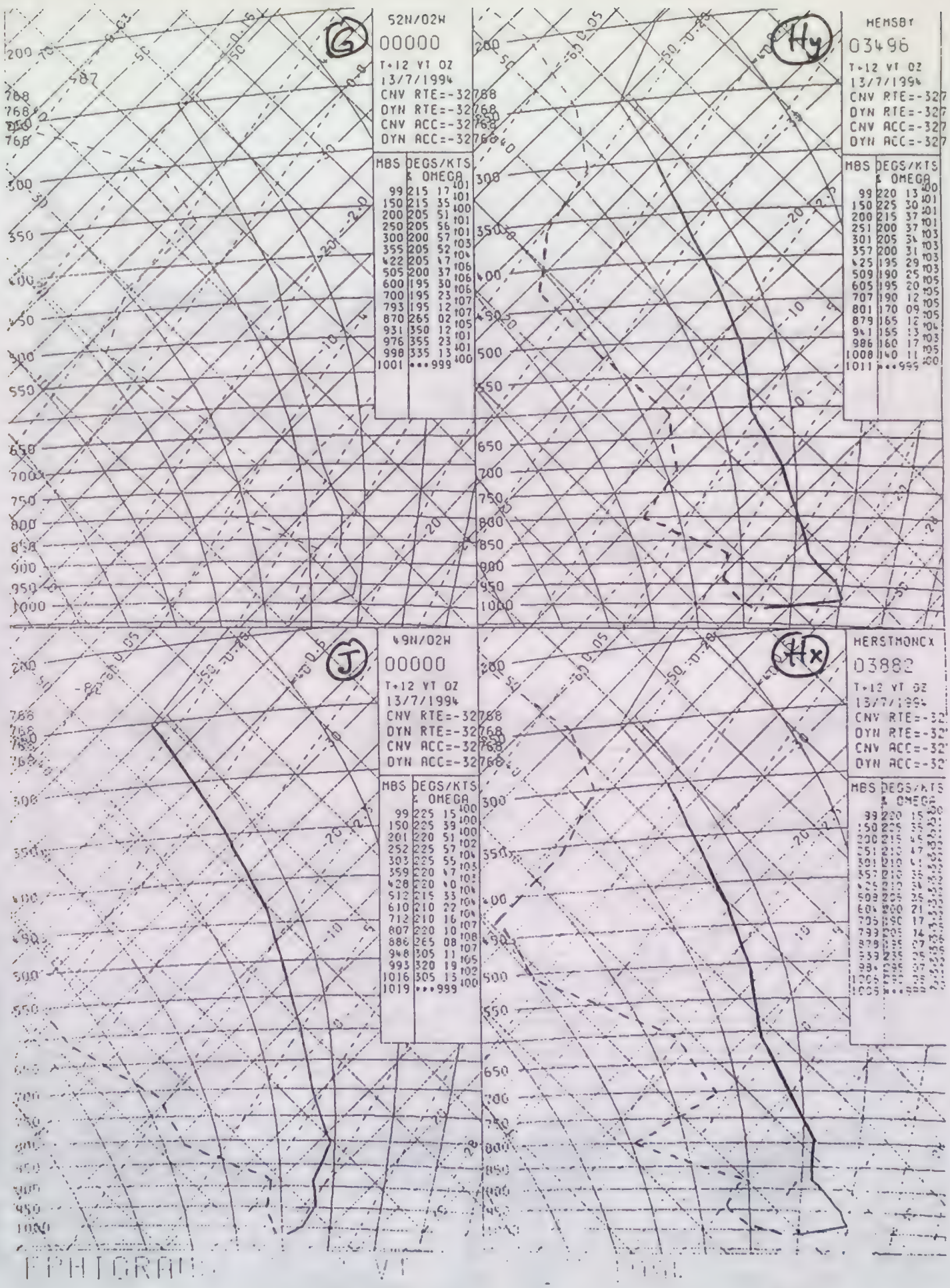


Fig. 4.4.6 LAM soundings from GLOSS run at T+12 (13/0000). Station locations are shown in Fig. 4.3.1(a).

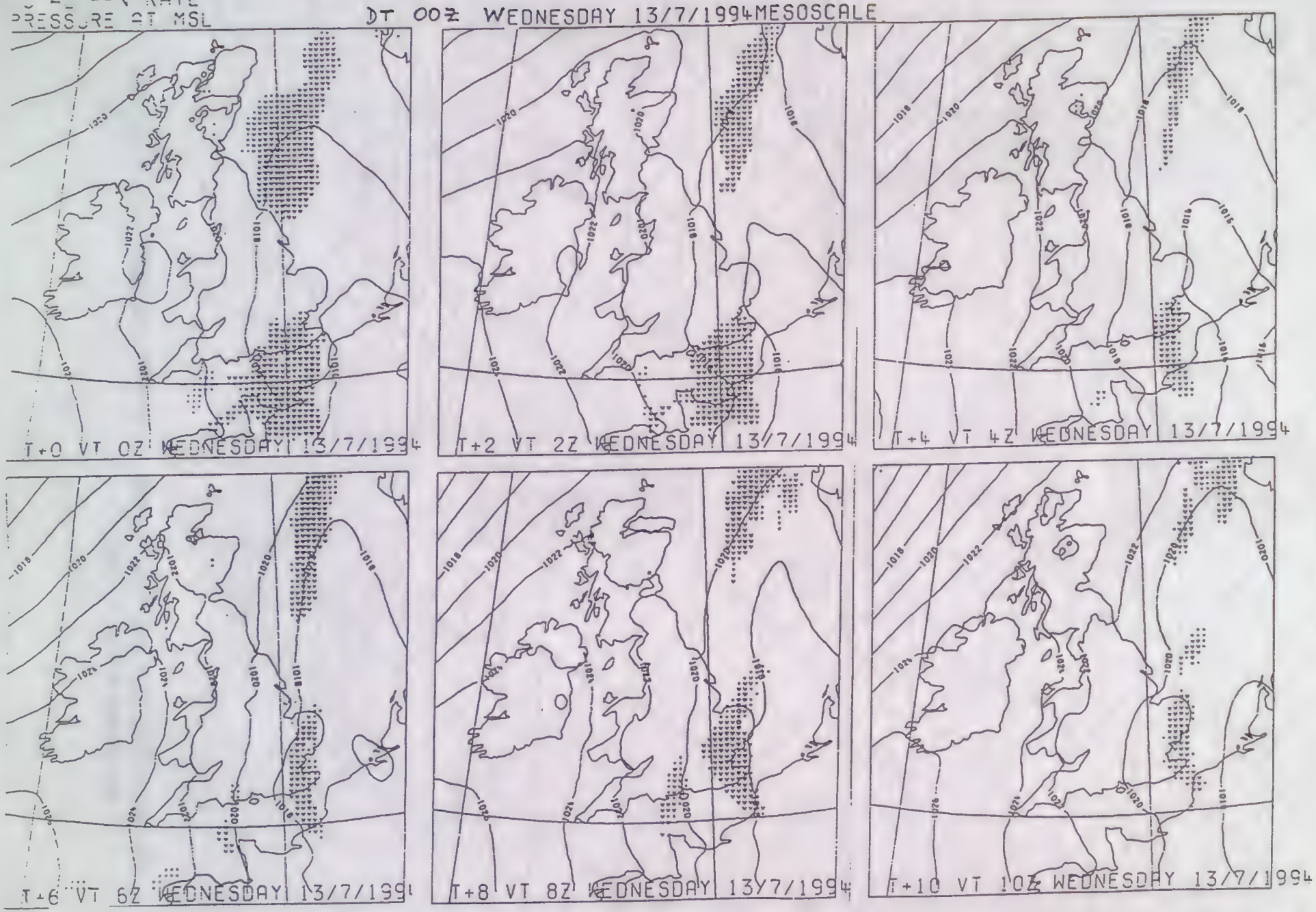


Fig. 4.5.1 Mesoscale forecast, data time 13/0000, showing area of showers.
Symbols as in Fig. 4.2.1

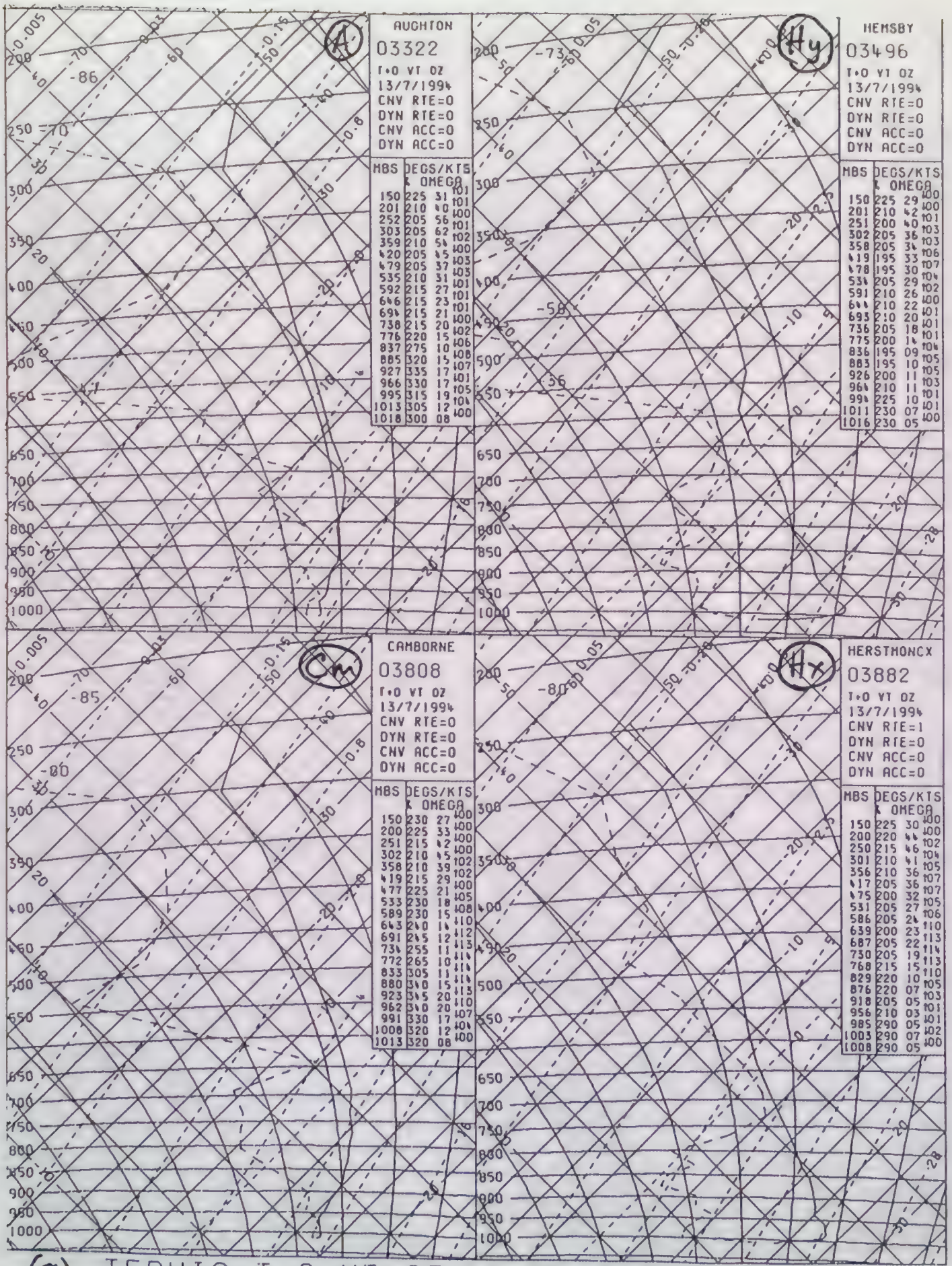
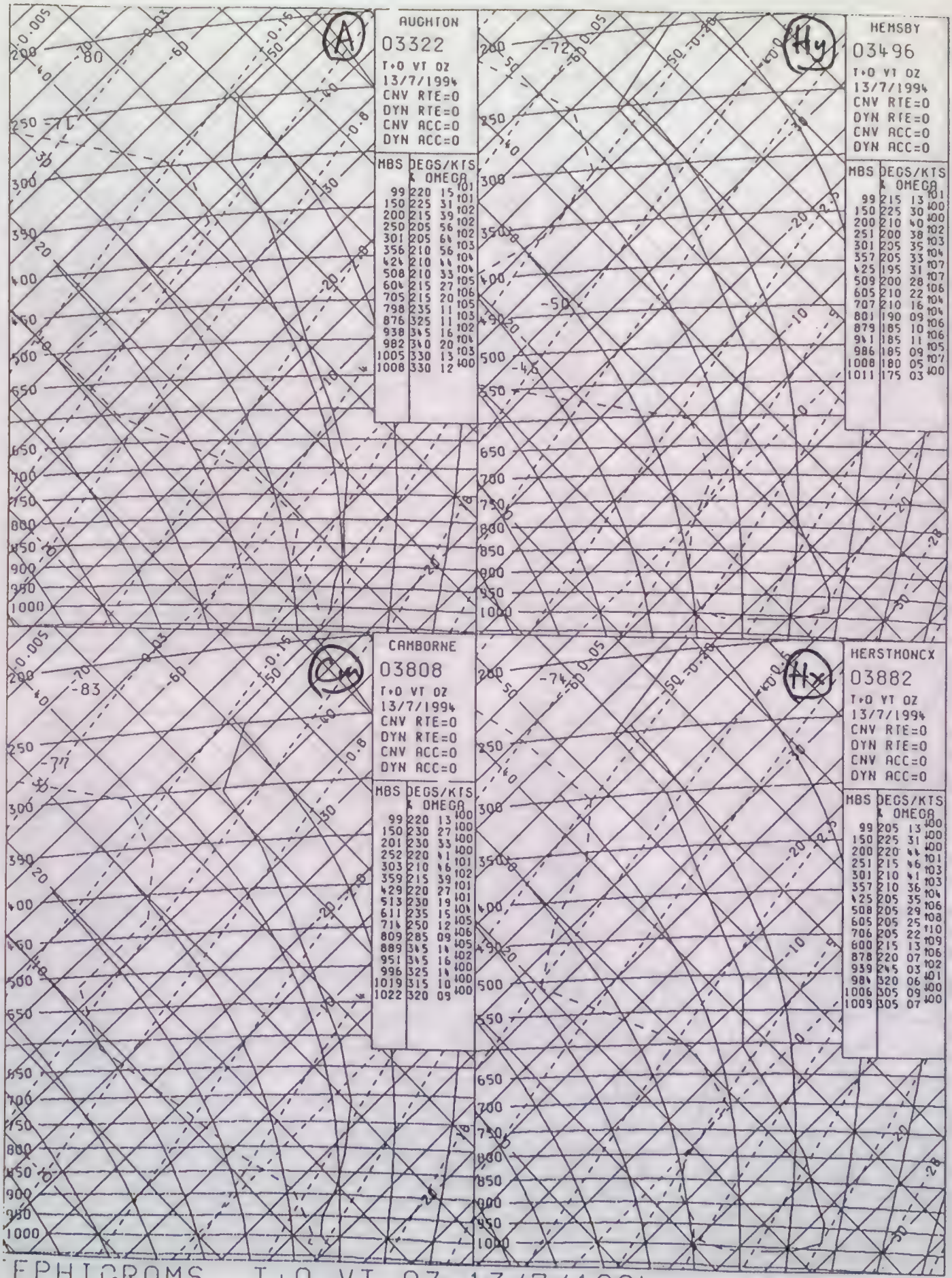


Fig. 4.5.2 T+0 soundings for the southern UK at 13/0000 from (a) MES and (b) LAM. Notice the higher humidity and ascent at Hx in the MES. Station locations are shown in Fig. 4.3.1.



EPHIGRAMS T+0 VT 0Z 13/7/1994

Fig 4.5.2(b)

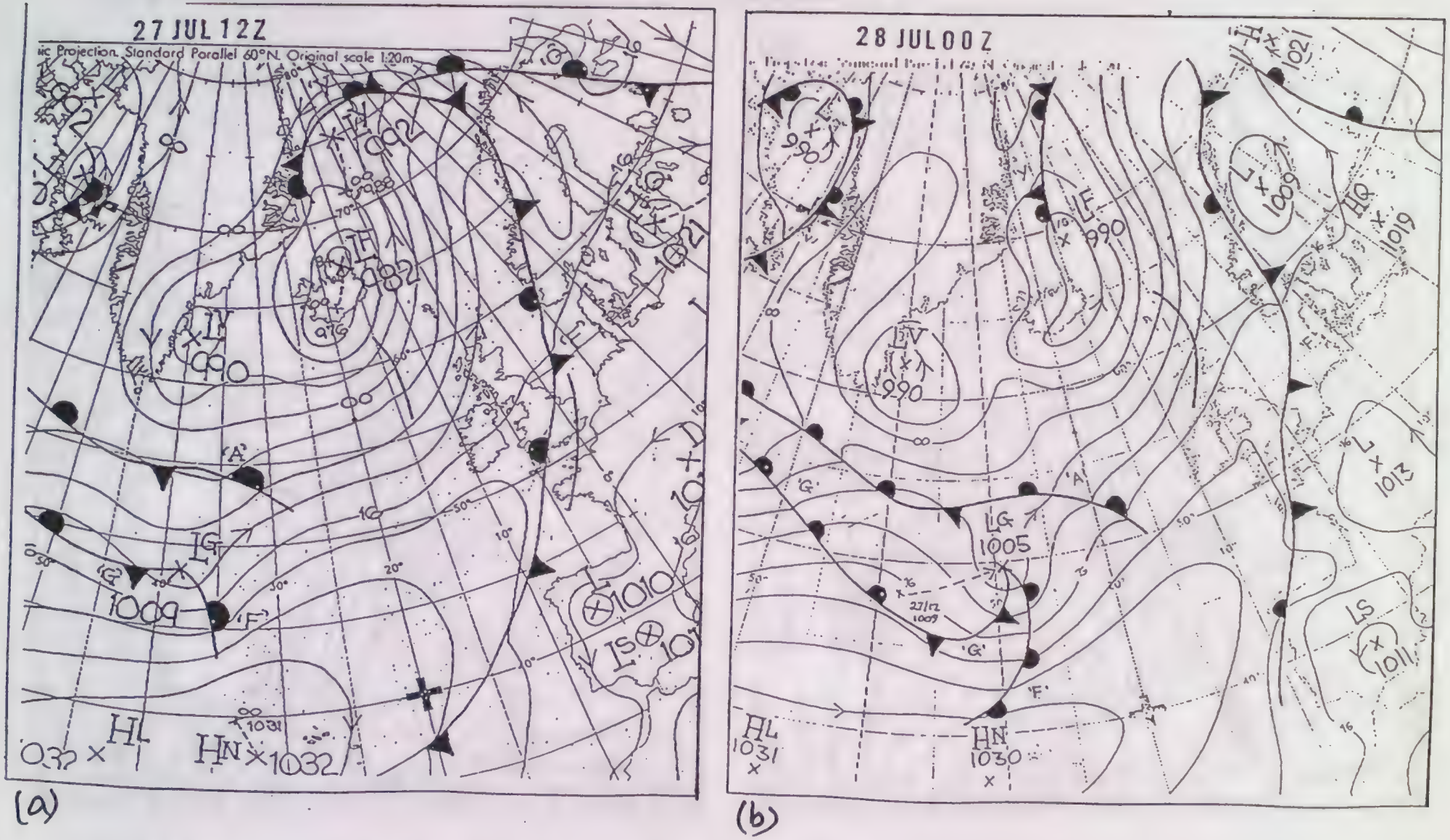


Fig. 5.1.1 Surface analyses at (a) 27 July 1994 1200, (b) 28 July 1994 0000.

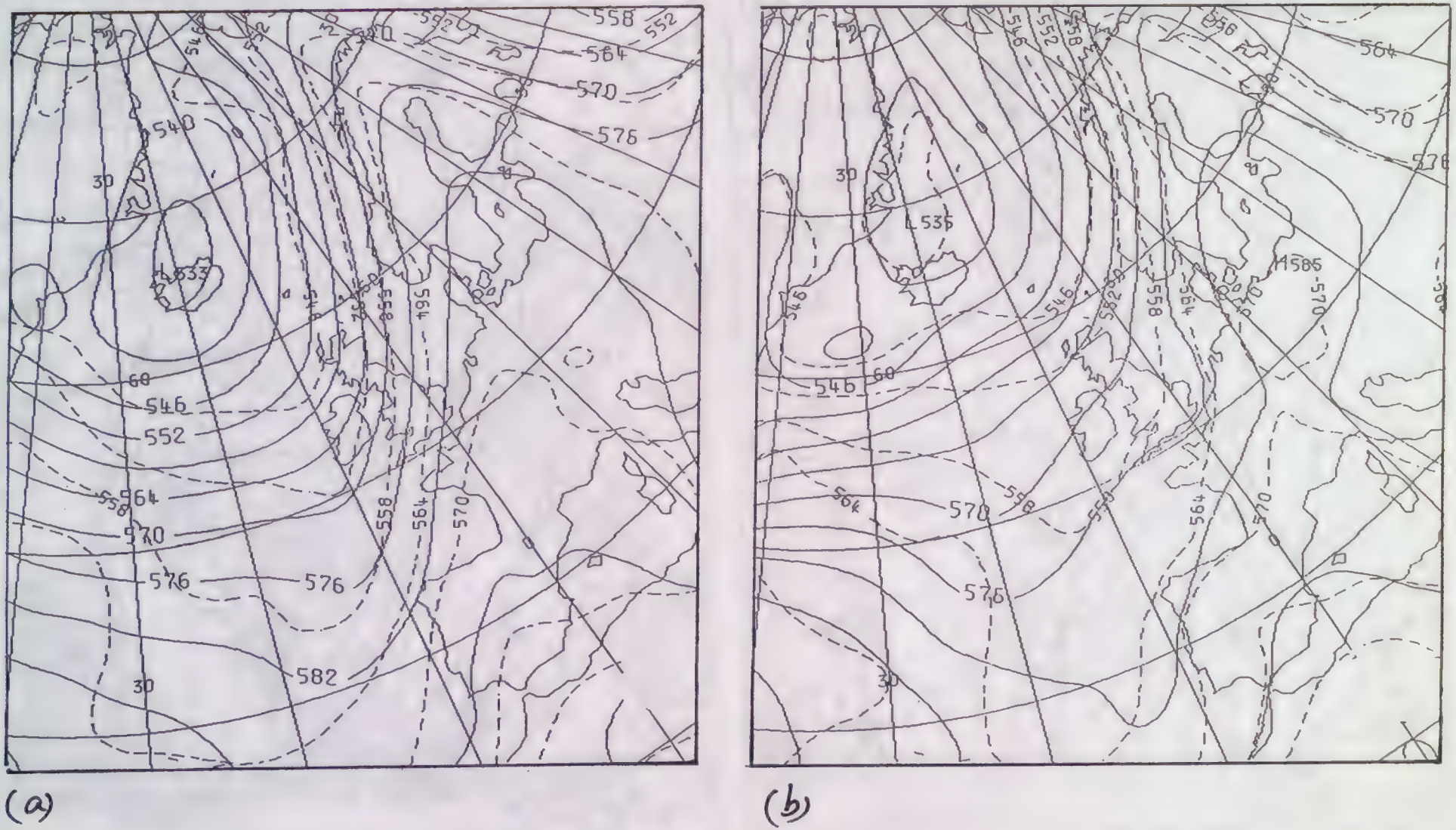


Fig. 5.1.2 LAM 500 hPa and thickness analyses on (a) 27 July at 1200 (b) 28 July at 1200. Dashed lines are 1000 to 500 hPa thickness in dam.

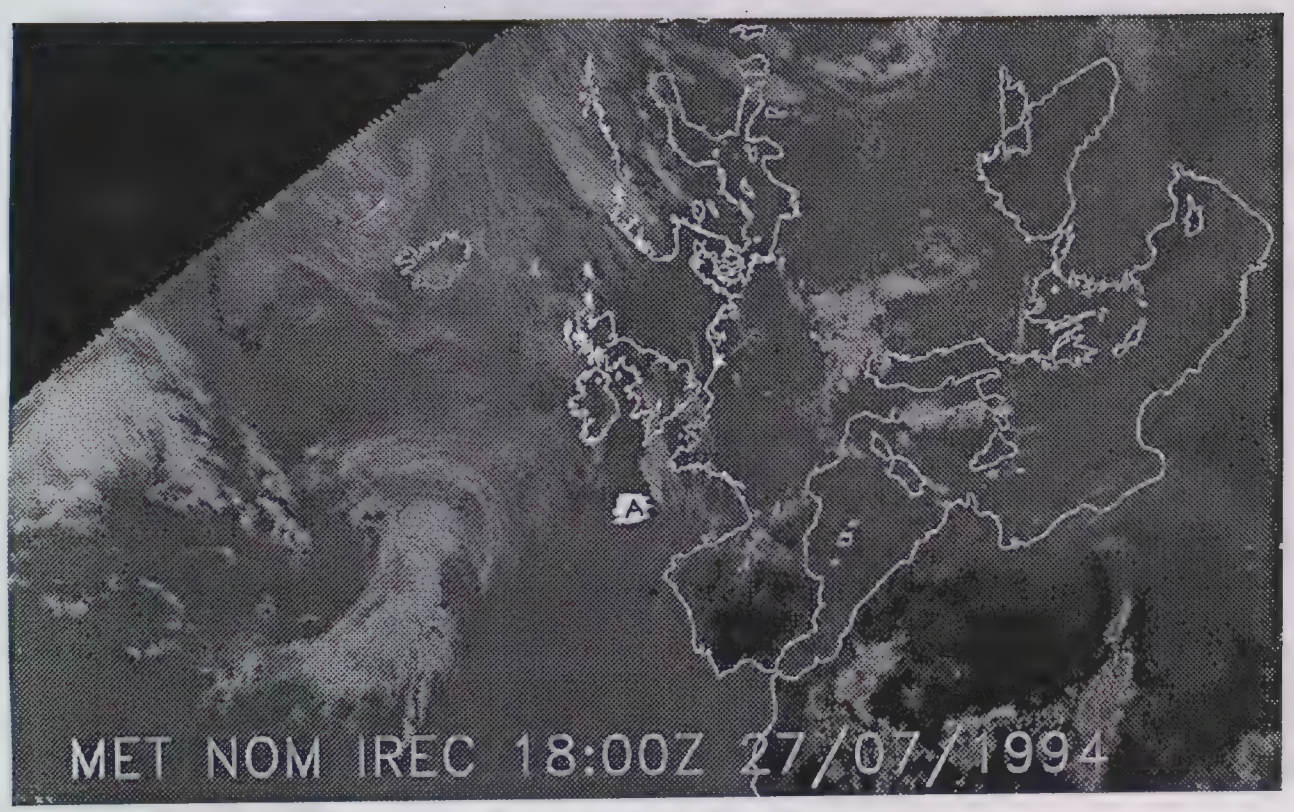


Fig. 5.1.3 IR Meteosat image at 27/1800 showing anvil cirrus streaming northwards from thunderstorms over Biscay at A.

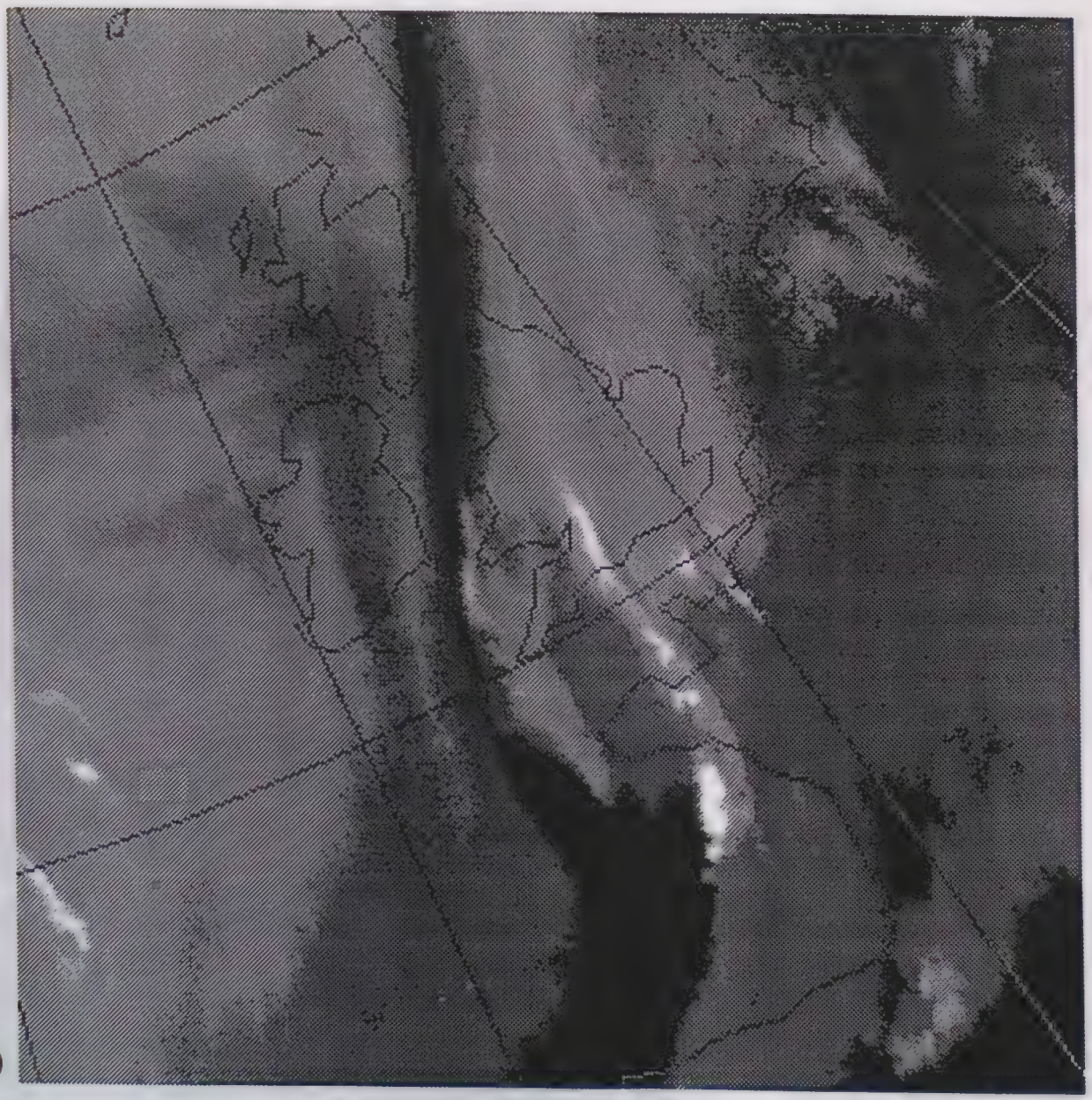


Fig. 5.1.4 Meteosat WV images for July 1994 showing the relationship between the Cb development and the dark slot. (a) 27/2130, (b) 28/0030, (c) 28/0330, (d) 28/0630.

Meteosat WV 28 July 1994 0030Z

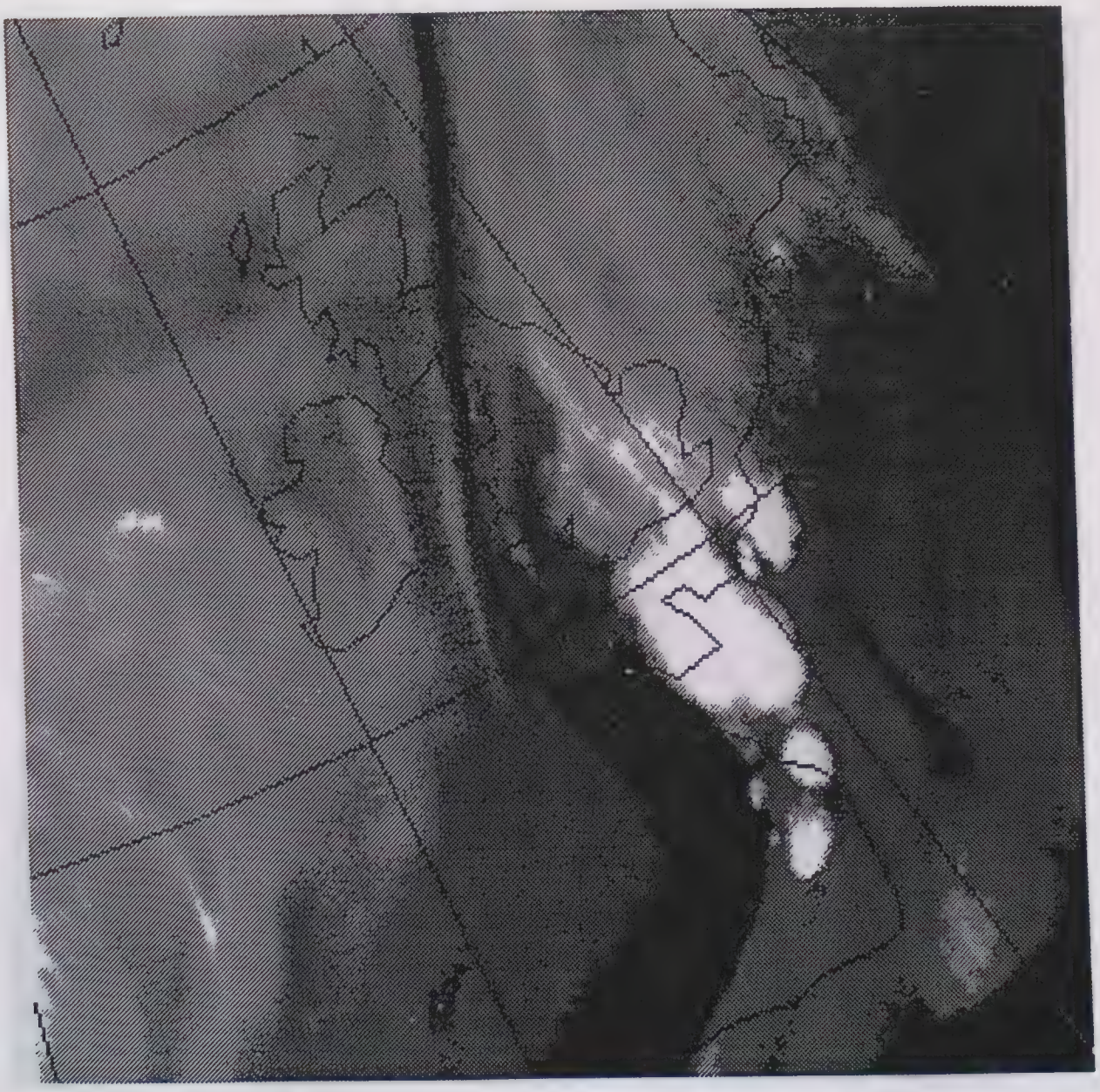


Fig 5.1.4 (b)

Meteosat WV 28 July 1994 0330Z

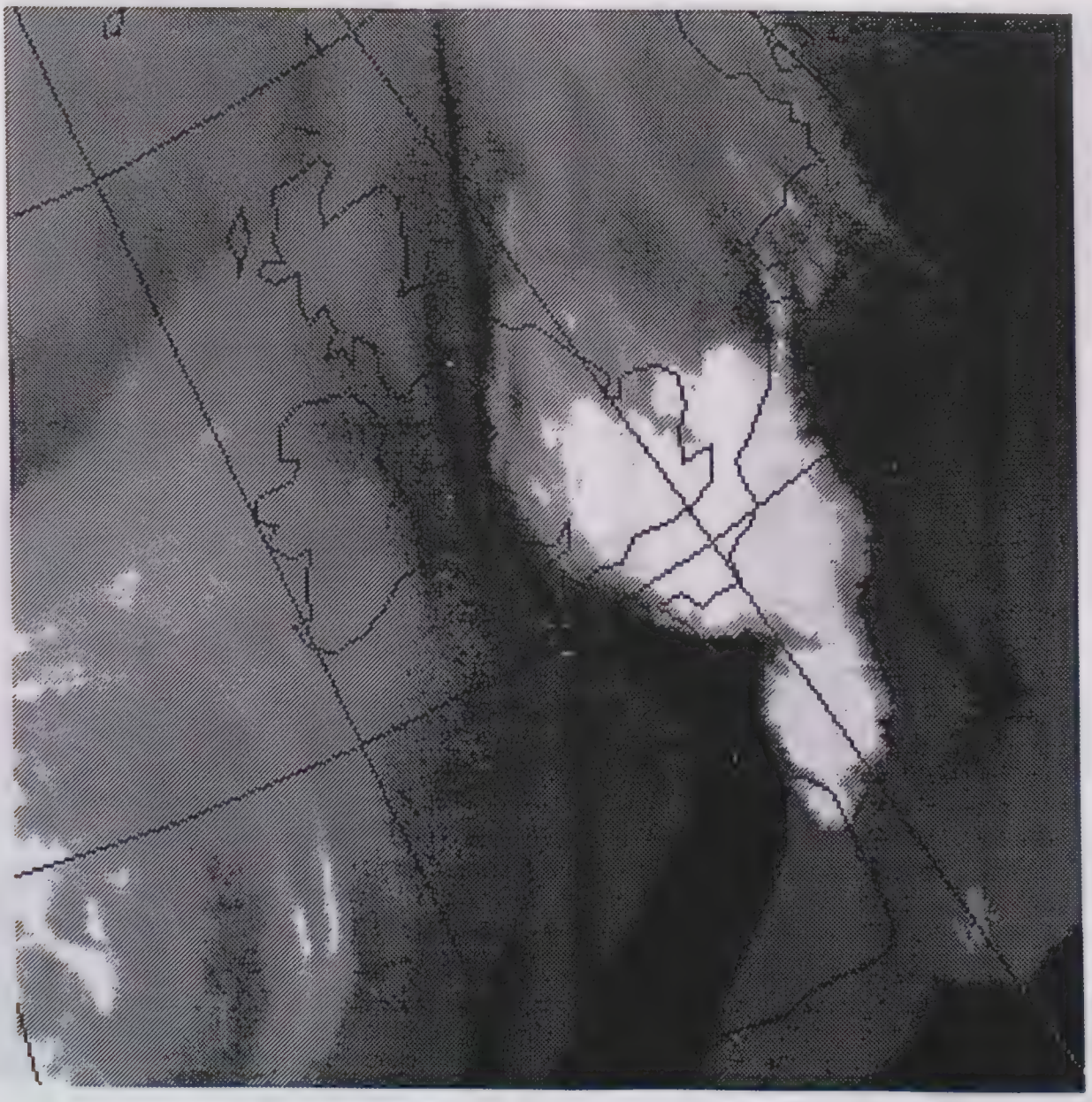


Fig 5.1.4(c)

Meteosat WV 28 July 1994 0630Z

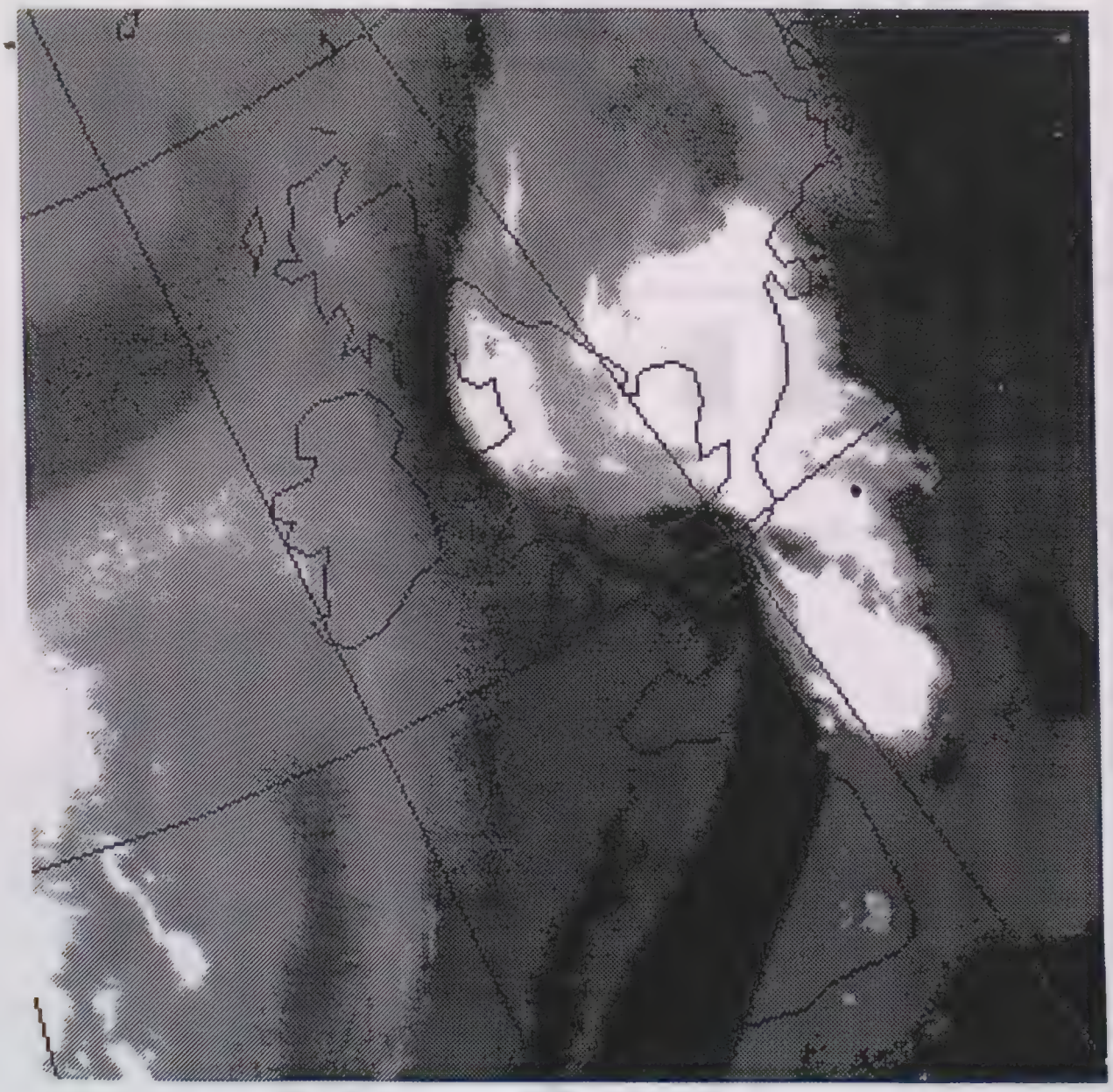


Fig 5.1.4 (d)

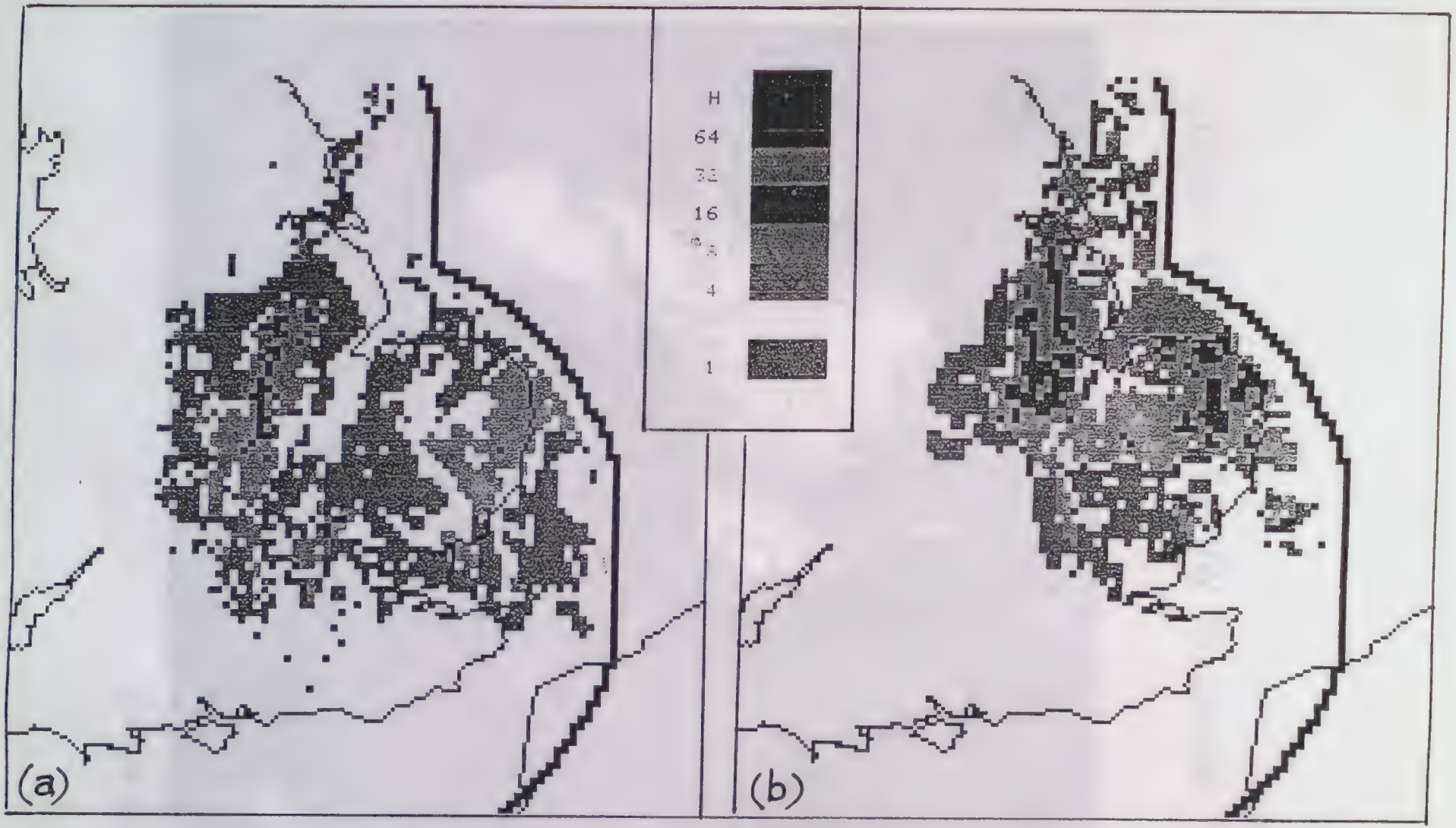


Fig. 5.1.5 UK composite weather radar image for (a) 28/0800 and (b) 28/1000. Rainfall rates peak at over 32 mm/hr. (The curved lines indicate the edge of the radar data.)

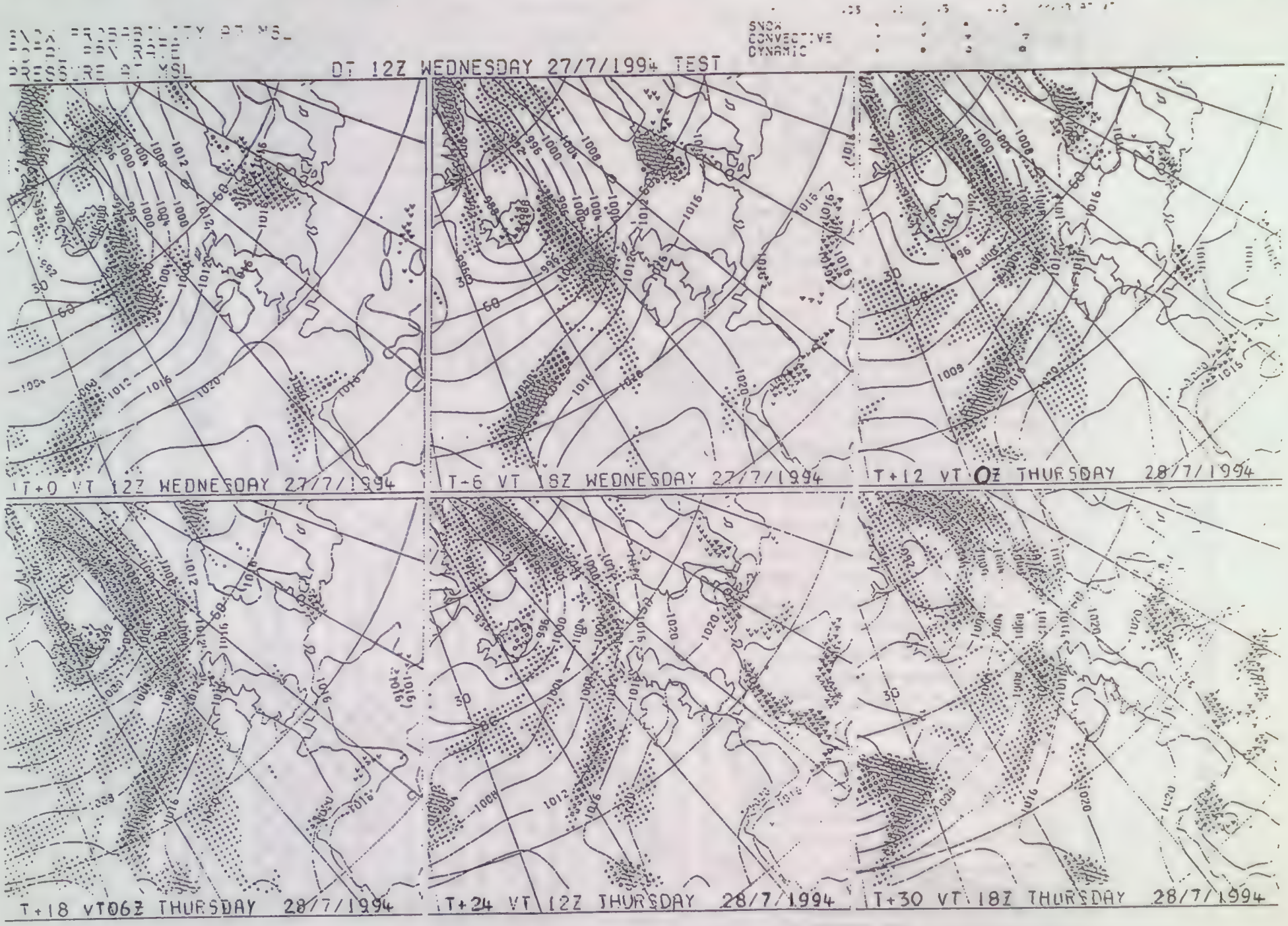


Fig. 5.2.1 LAM operational forecast from 27/1200, T+0 to T+30 showing no showers over southern England.

LAM T+18 forecast of 250-mb winds with actual winds superimposed

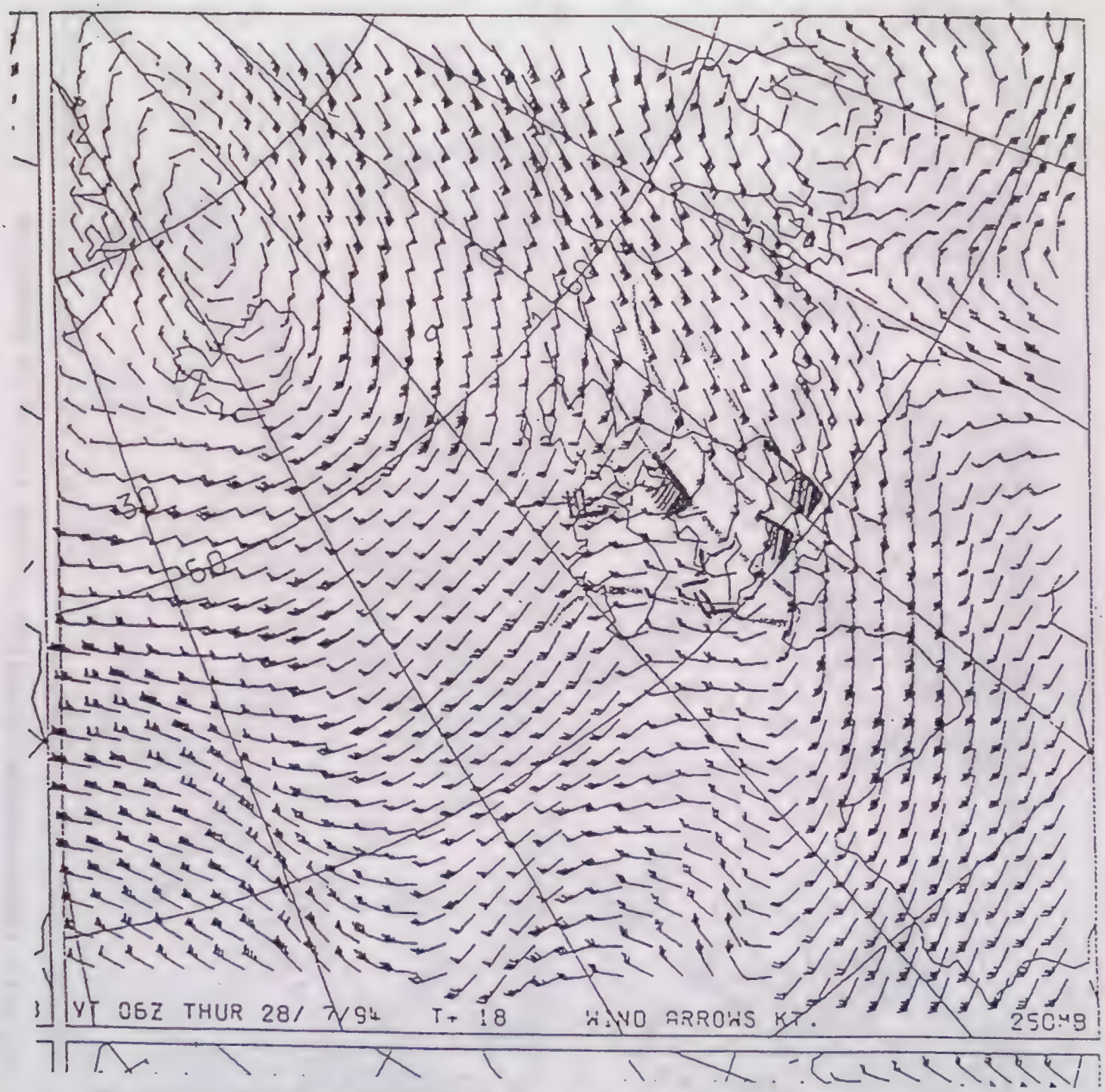


Fig. 5.2.2 LAM 250 hPa wind forecast for 28/0600 from data time 27/1200.
Superimposed are radio-sonde winds at 28/0600.

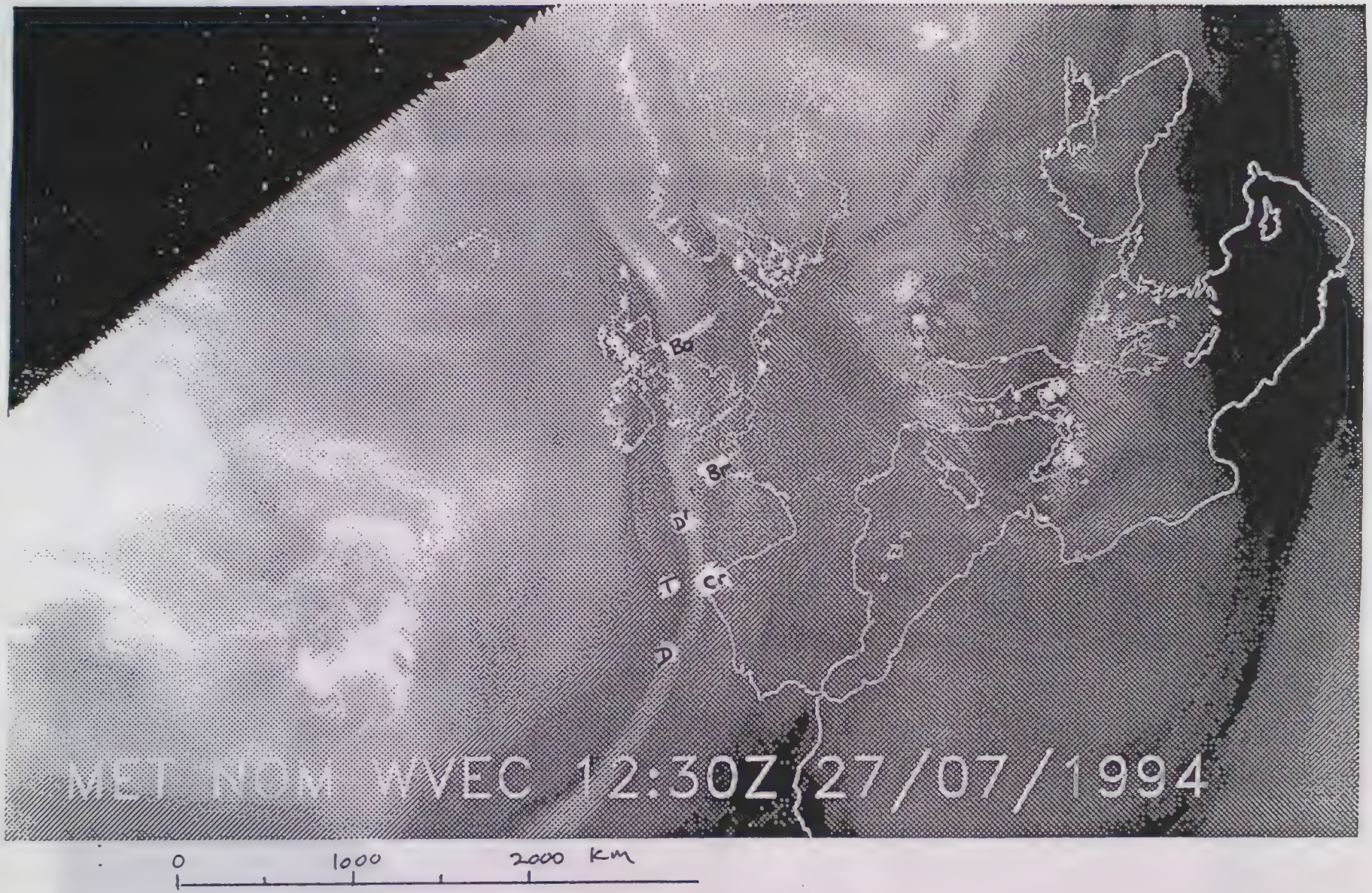


Fig. 5.3.1 Meteosat WV image at 27/1230. Cr is Corunna, Br is Brest and Bo is Boulmer. T indicates an upper trough and DD' a deformation zone.

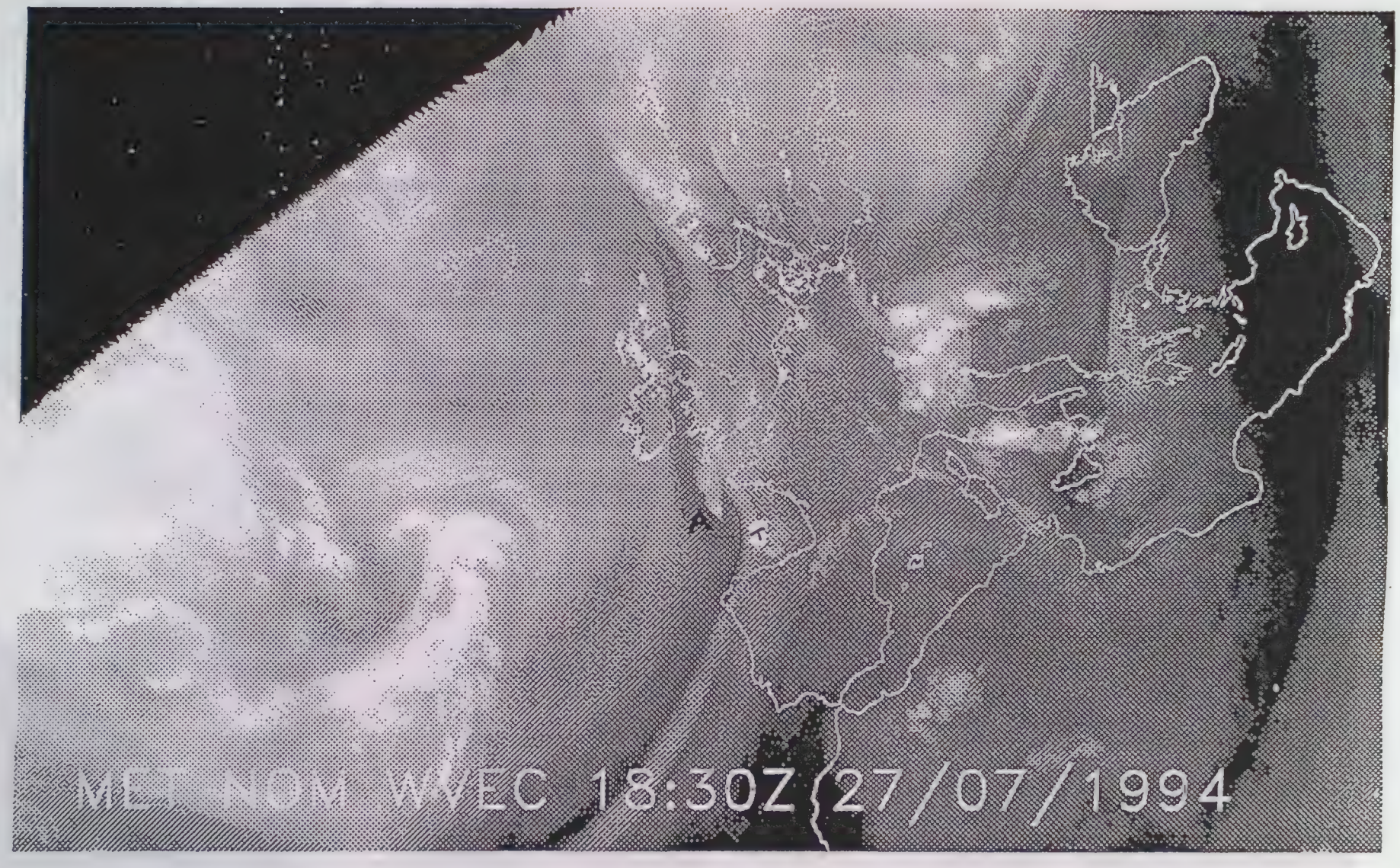
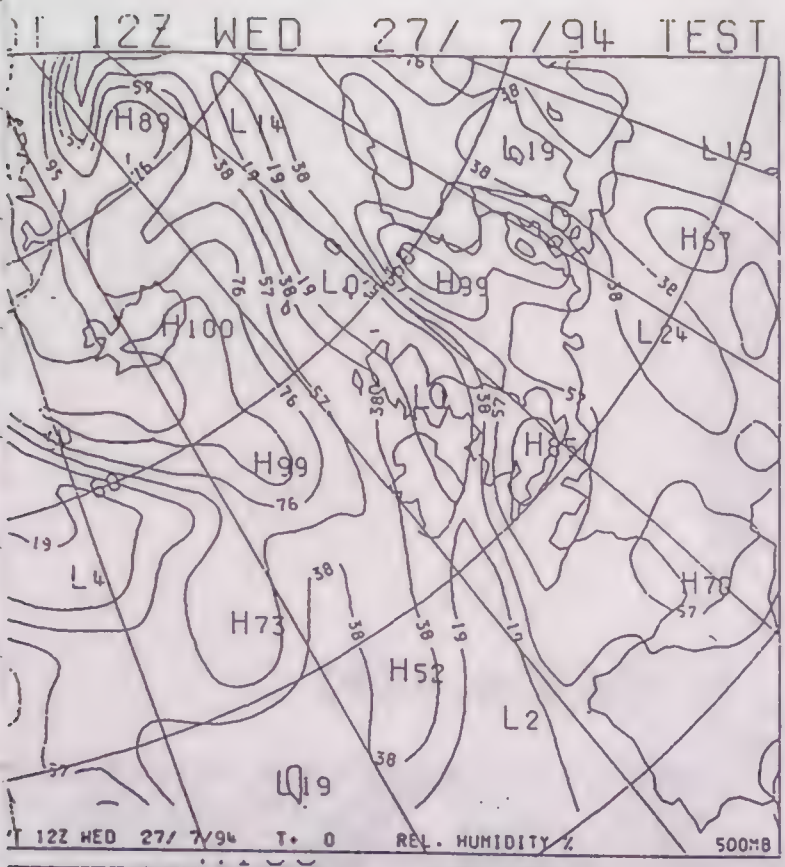
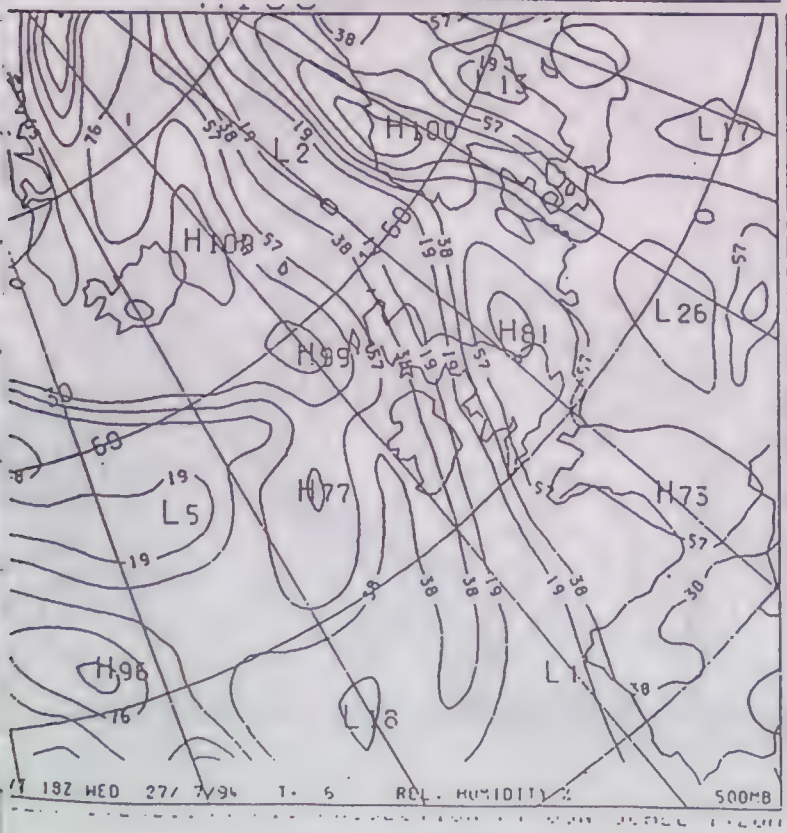


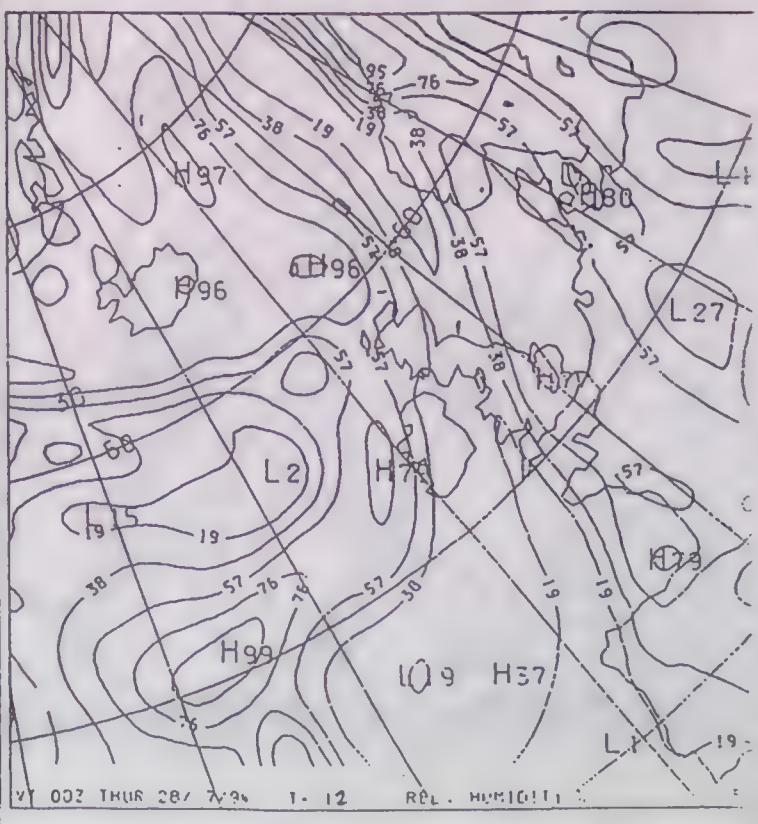
Fig. 5.3.2 Meteosat WV image at 27/1830. T is an upper trough and A is the anvil cirrus that was misinterpreted in the CTWs.



(a)

Fig. 5.4.1 LAM 500 hPa relative humidity fields from data time 27/1200 (a) operational, (b) Experiment 1, showing the difference in RH at T+0, T+6, T+12 when Corunna humidities were removed. (Symbols as in Fig. 4.2.1.)





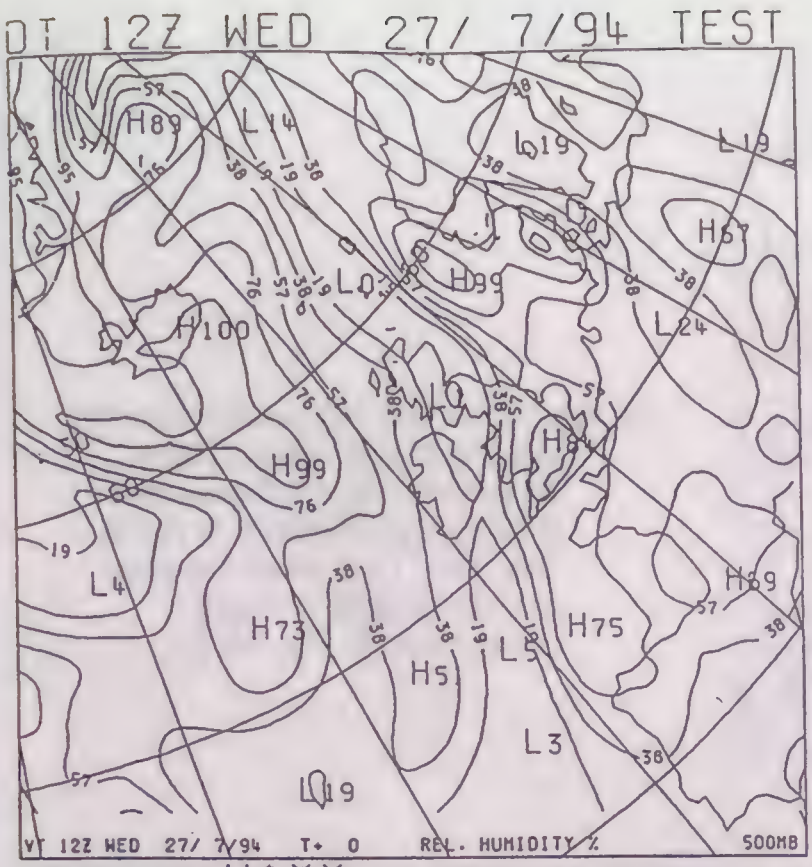
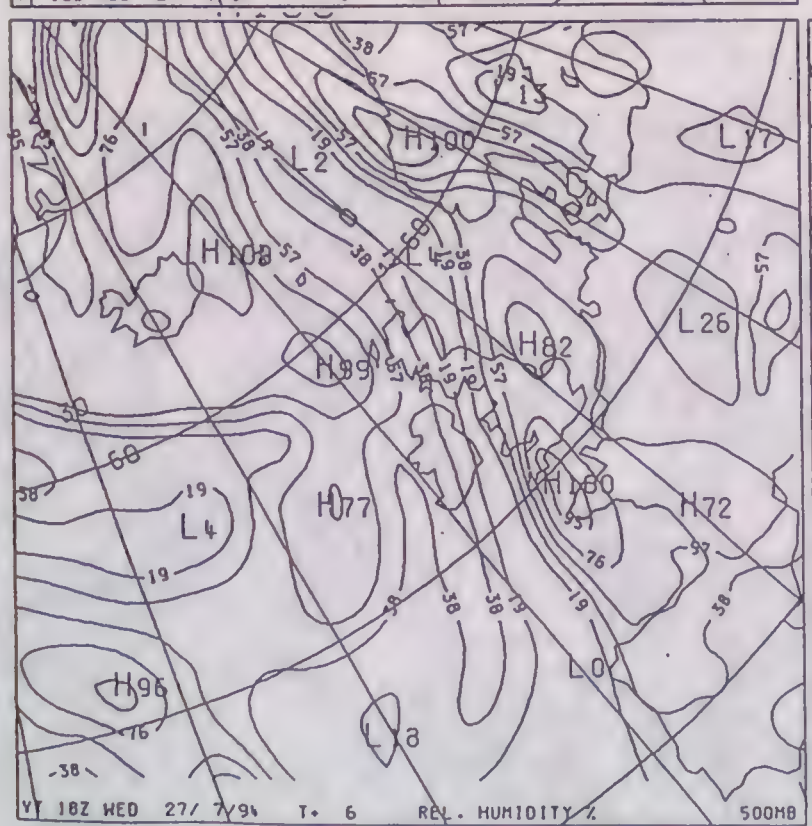

DT 12Z WED 27/ 7/94 TEST
VT 12Z WED 27/ 7/94 T+ 0 REL. HUMIDITY % 500MB

Fig 5.4.1 (b)


VT 18Z WED 27/ 7/94 T+ 6 REL. HUMIDITY % 500MB

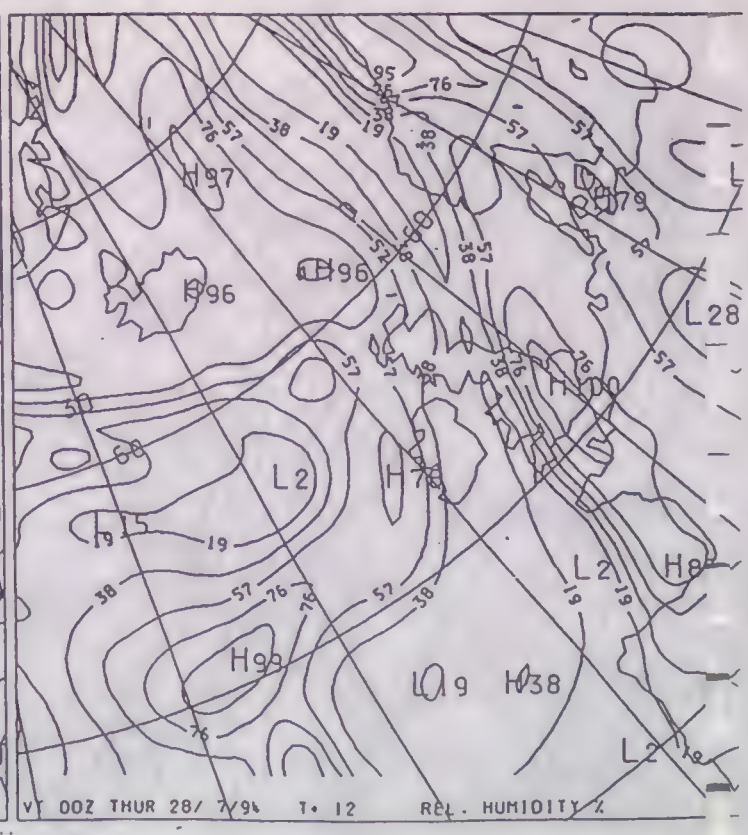
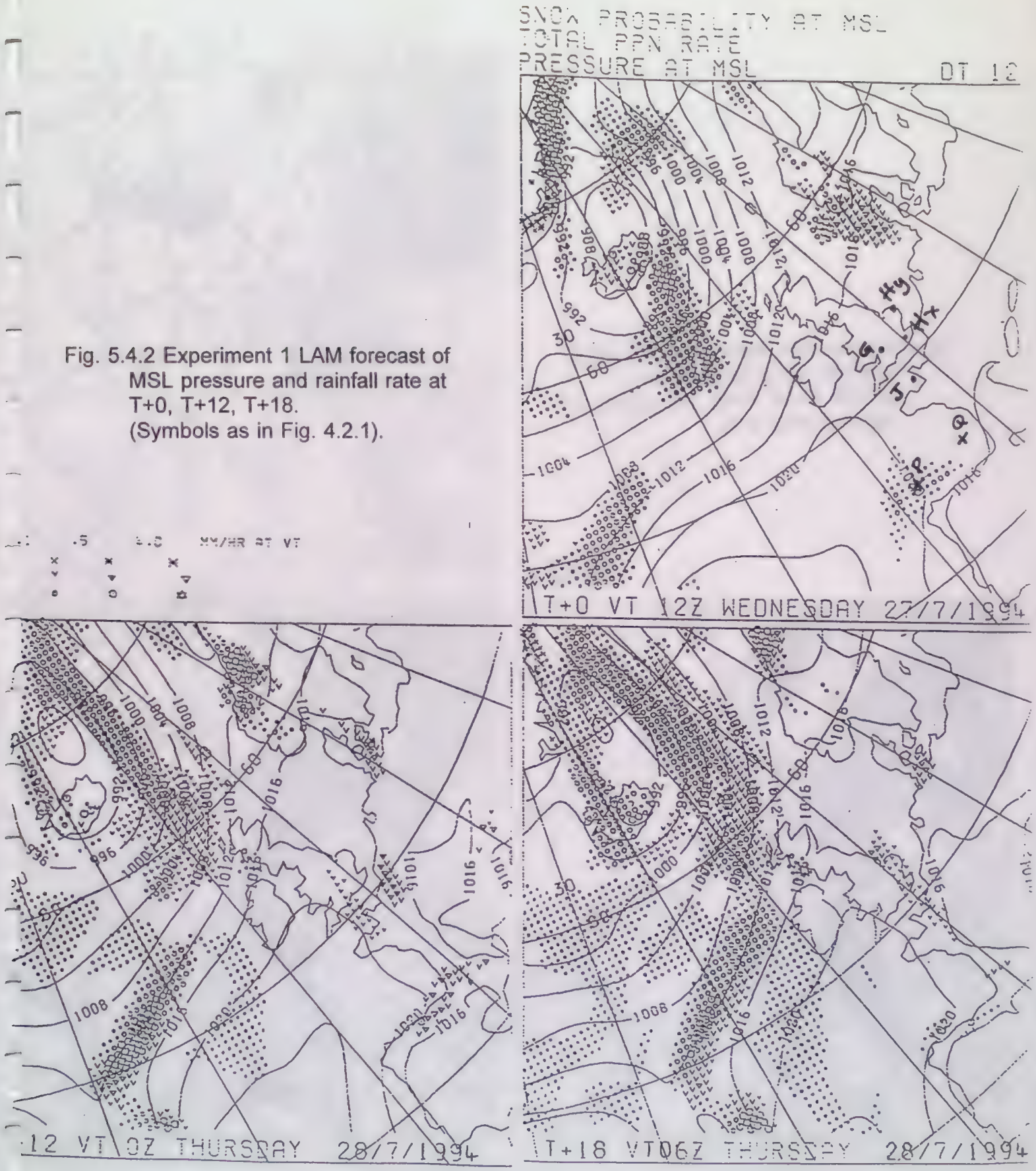

VT 00Z THUR 28/ 7/94 T+ 12 REL. HUMIDITY %

Fig. 5.4.2 Experiment 1 LAM forecast of MSL pressure and rainfall rate at T+0, T+12, T+18.
(Symbols as in Fig. 4.2.1).



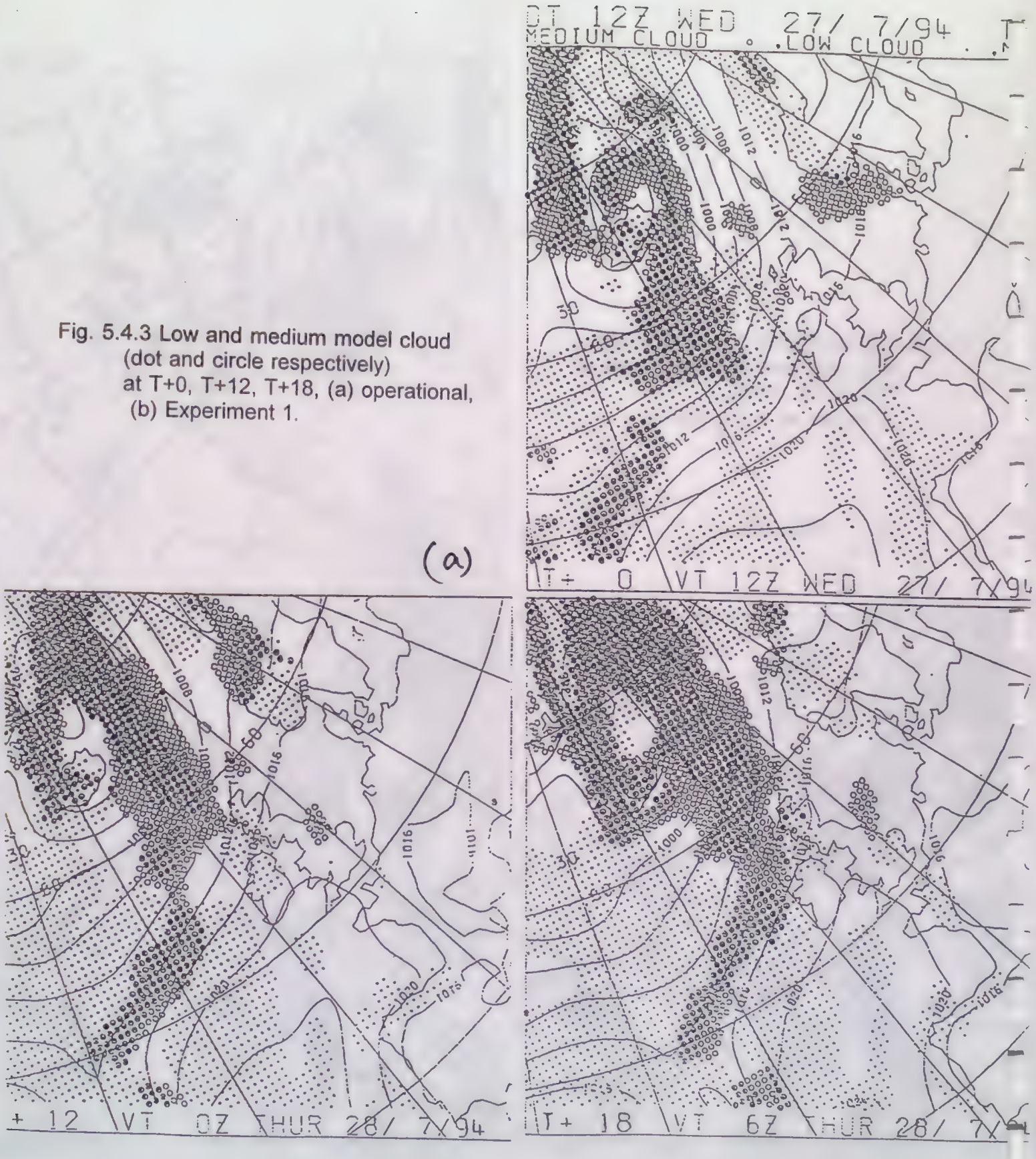


Fig. 5.4.3 Low and medium model cloud (dot and circle respectively) at T+0, T+12, T+18, (a) operational, (b) Experiment 1.

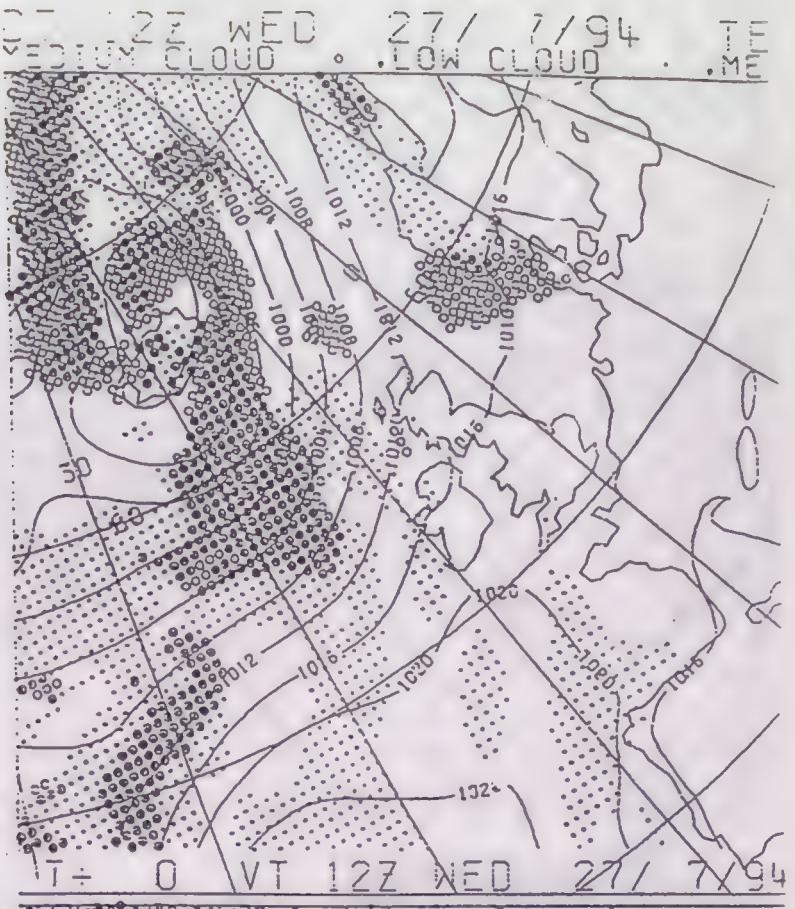
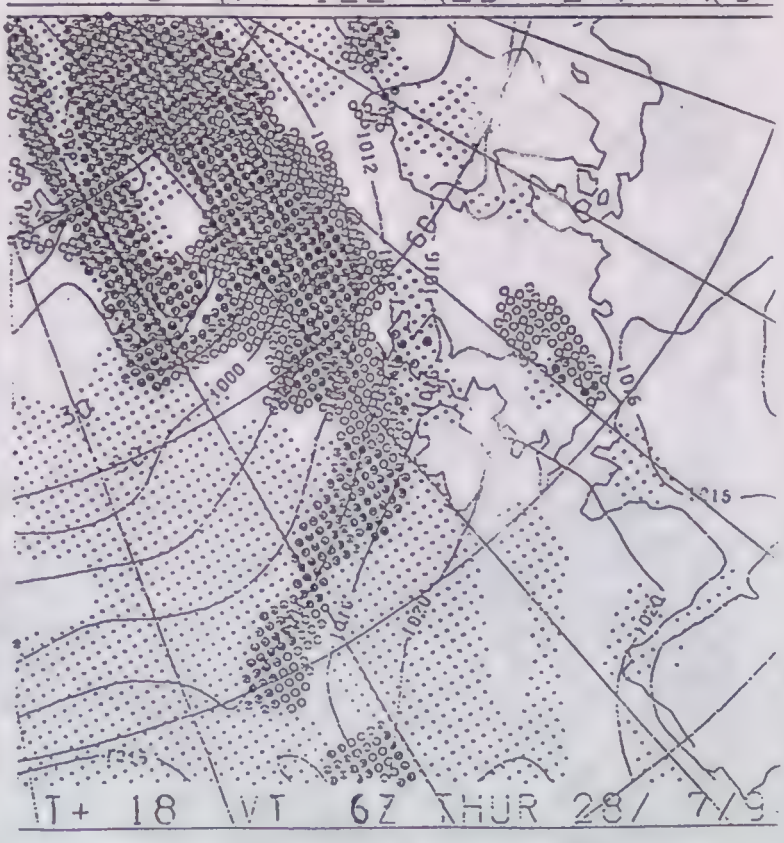

MEDIUM CLOUD
LOW CLOUD
T+ 0 VT 12Z WED 27/ 7X94

Fig 5.4.3 (b)

T+ 12 VT 0Z THUR 28/ 7X94


T+ 18 VT 6Z THUR 28/ 7X9

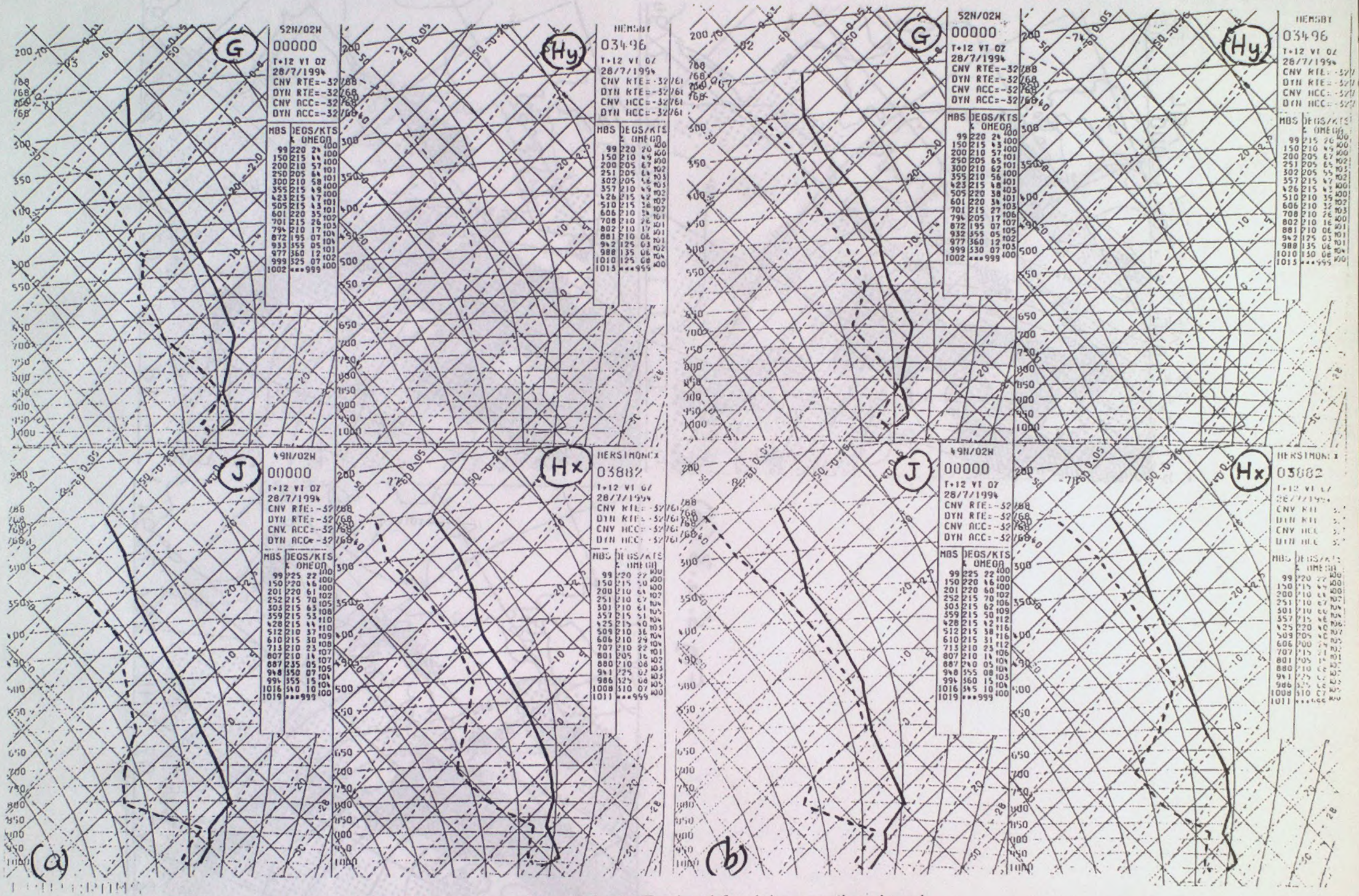


Fig. 5.4.4 Model soundings for southern England for (a) operational and (b) Experiment 1 at T+12 showing the increased humidity and instability in

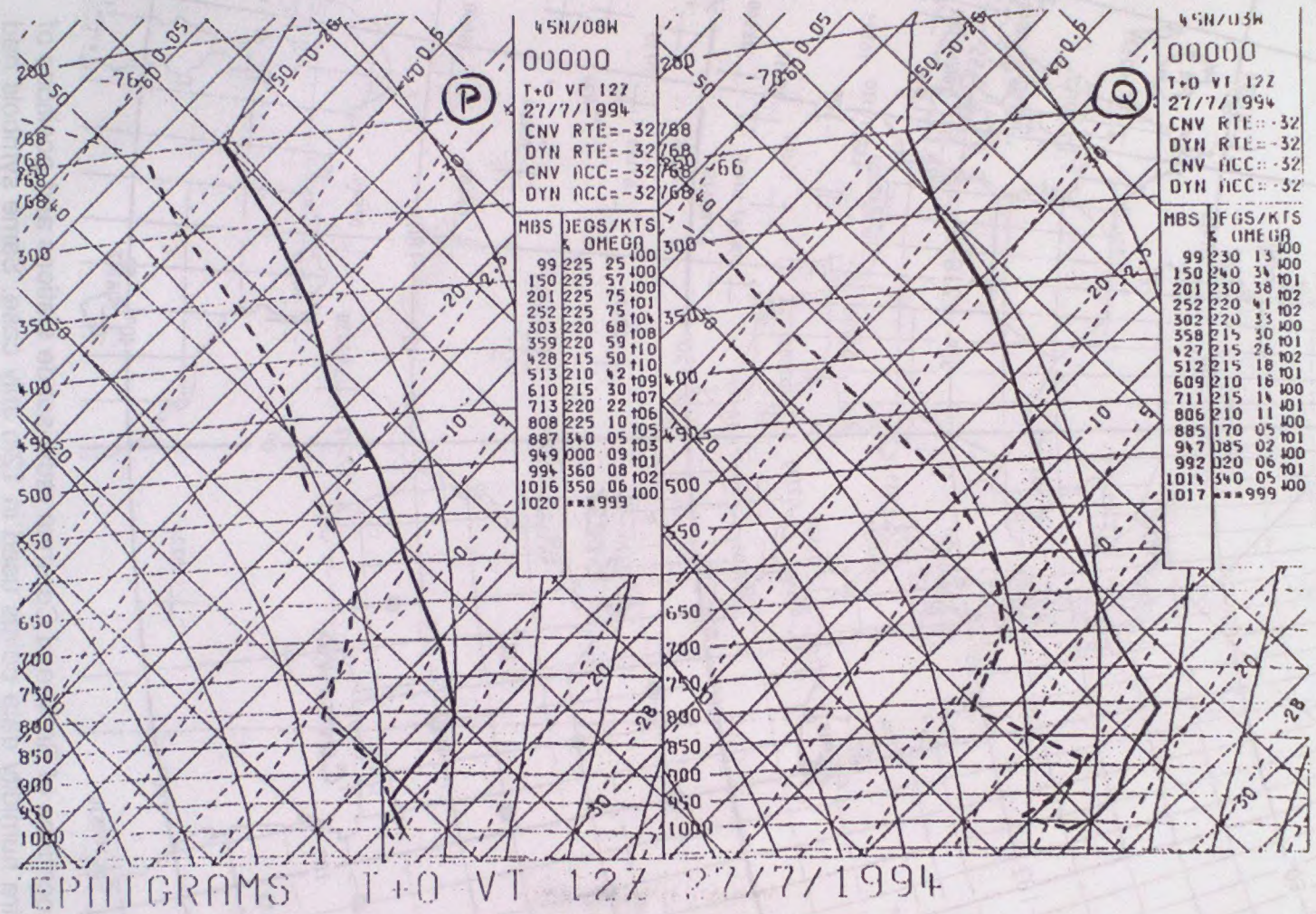
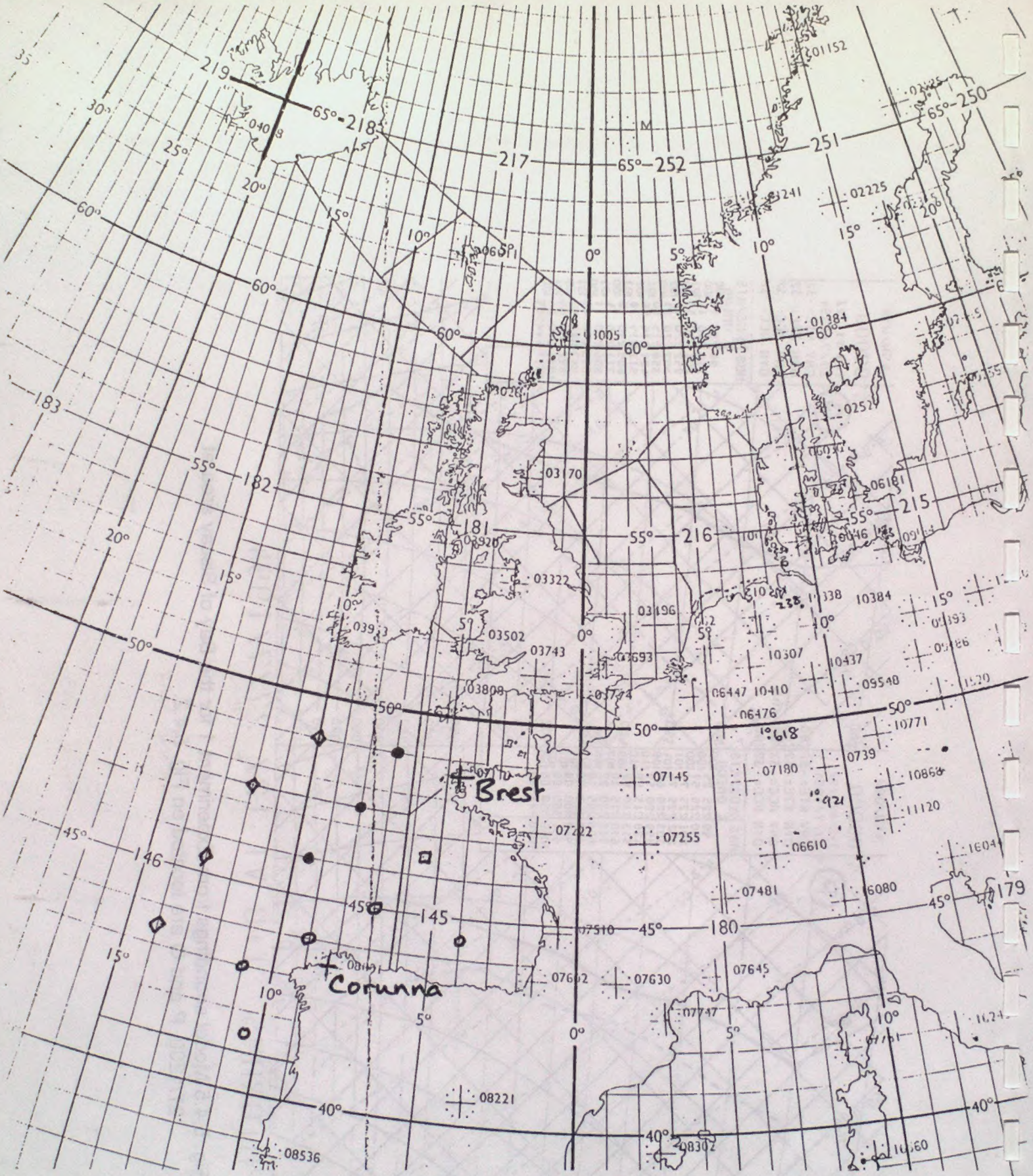
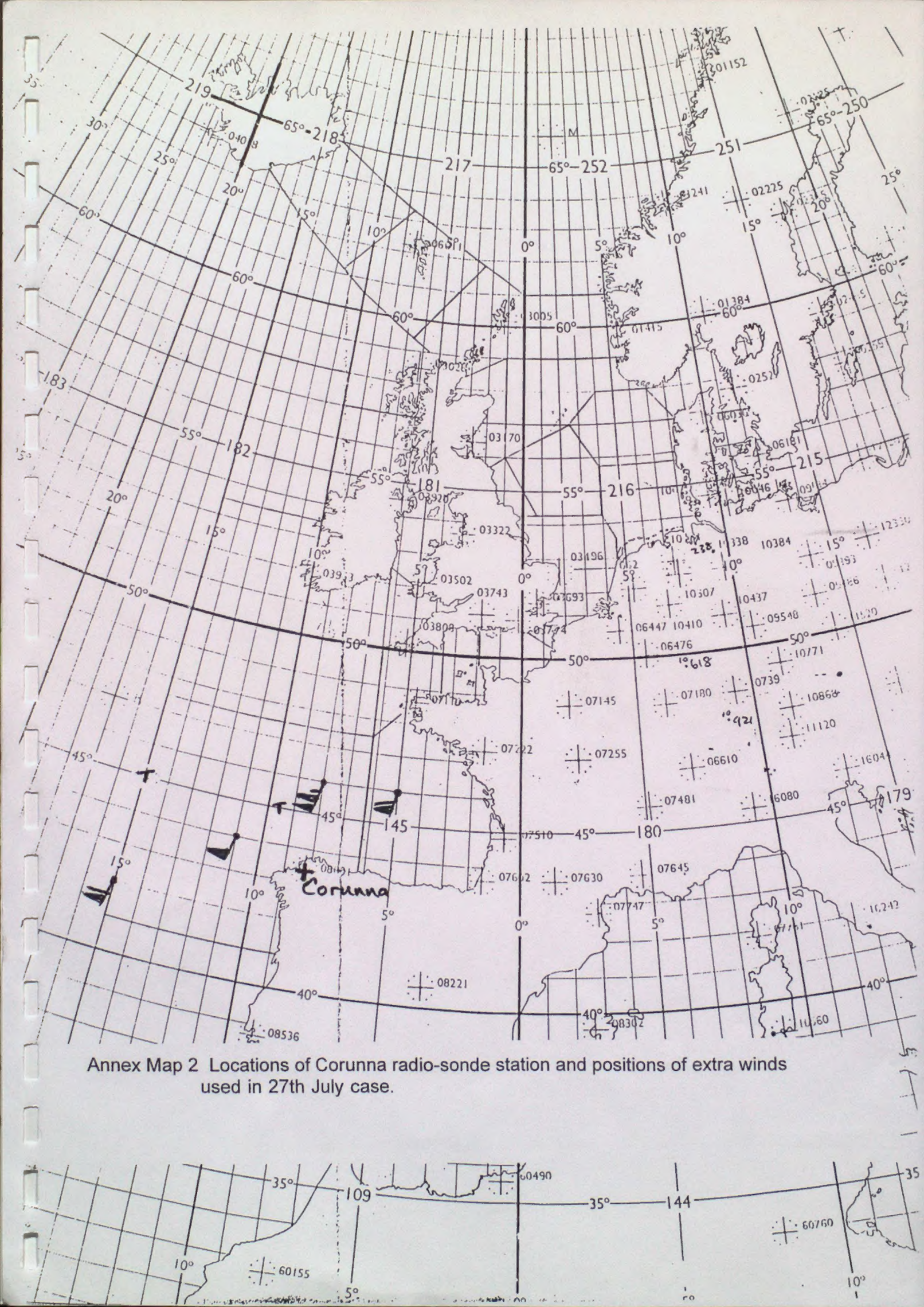


Fig. 5.4.5 Model soundings from Experiment 1 for the Bay of Biscay area at 27/1200. P and Q are located on Fig. 5.4.2.



Annex Map 1 Locations of Brest and Corunna radio-sonde stations and positions of extra humidity data points used in 12th July case. Same symbols had the same humidity inputs.



Annex Map 2 Locations of Corunna radio-sonde station and positions of extra winds used in 27th July case.